The TREND IN ENGINEERING

at the University of Washington

In this issue:

ULTRAMODERN STEAM PLANTS FOR THE PACIFIC NORTHWEST POWER SYSTEM

BEHAVIOUR OF CELLULOSES IN SODIUM HYDROXIDE SOLUTIONS

THE INTERMITTENT SUPERSONIC WIND TUNNEL

STRENGTH OF TRUSSED COLUMNS

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THE ENGINEERING EXPERIMENT STATION

LET'S LOOK AT ENGINEERING EDUCATION

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Professor of Civil Engineering and Chairman of the University of Washington associated committee coordinated with the ASEE Committee on Improvement of Engineering Teaching

T. H Campbell

The study of education is very old: by the early Pleistocene period primitive man had developed formalized patterns for the training of the young. As is true of much of our culture, many of our teaching philosophies stem from those of Ancient Greece. Aristotle wrote extensively concerning education, as did Plato during the fourth century B. C. in his **Republic** and **Laws.** Even engineering education is not young. In 96 A.D. the Roman, Quintilian, wrote about the training of engineers, reflecting the educational requirements caused by the great construction program of his empire.

Yet in many ways engineering education as we know it is relatively new. The rapid technological advances of the past two centuries have required more and more specialization. As a result, a growing amount of technical course content has tended to create curricula lacking in the broader aspects of true professional education. The increasing scope of requirements placed upon training for the young engineer inevitably has led to change and experimentation.

At present there is much stir and reappraisal in engineering education. The requirements of industry, of national defense, and of modern living are demanding increased technical knowledge of the young engineer, while at the same time he is expected to have greater awareness of his place in the social, economic, and cultural structures of his civilization. Industry and the profession are concerning themselves more directly with the problem of training properly an adequate supply of graduate engineers, both at the college level and during the first "in training" period of employment. An increasing amount of opinion is being crystallized around the concept that it is education's job to teach fundamentals and that it should be left to the employer to teach the application of these fundamentals. There is a new realization that a professional man should not only be technically competent, but creative and aware of his responsible position in our culture, as well; in short, that many who are called professional engineers are in reality nothing more than skilled technicians. Also, recently, the colleges are feeling the effect of new teaching philosophies in the high schools of this country, where students are getting less instruction in mathematics and the sciences in order to make way for courses designed to prepare them for living in our present complex society. The entering freshman may have a broader and more sophisticated educational background than his father had at the same age, but his mastery of the "three R's" tends to be considerably less. The engineering educator, in reacting to these many trends and pressures, is attempting to find better approaches to training the aspiring young engineer to meet the new situations.

It's interesting to look at the varied programs, techniques, and proposals that have resulted. One idea which has been expressed is that of having undergraduate instruction on such a fundamental level that there would be essentially only one curriculum for all engineering students, reserving any specialization for postgraduate study. Professor John B. Wilbur of M.I.T. has questioned the traditional order of course material in civil engineering curricula and has asked consideration of an undergraduate program that would be designed to orient the student initially toward the functional, economic and social aspects of engineering as a comprehensive total, and finally to provide the scientific and technical background necessary to obtain solution to specific problems. Professor S. J. Mazur, of Nova Scotia Technical College, has stated his disagreement with Professor Wilbur's thought, and has voiced the belief that a sound progression of scientific training is necessary before the student becomes mature enough to grasp the broader scope of engineering. Another engineering teacher has published his view that engineers must have courses in management so that they may be qualified to take management positions. Some believe that in this country we should adopt the European system of higher education, which is aimed at obtaining a relatively small corps of gifted, highly competent engineers, and which awards or withholds degrees on the basis of comprehensive examinations after years of study. Professor R. K. Bernard of Rutgers University has presented an interesting analysis of the pros and cons of the American and European methods. There have been numerous approaches to the question: "Should our Universities train highly skilled engineering technicians as well as professional engineers?" along with the inevitable attempts to discriminate between the two by means of definitions and required curricula.

(Continued on page 15)

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgical, Ceramic Engineering
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. Results of major investigations are published in the form of bulletins and reports. Current research findings from the Station's fellowship projects, as well as accounts of its activities, appear in the quarterly journal, *The Trend in Engineering at the University of Washington*. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

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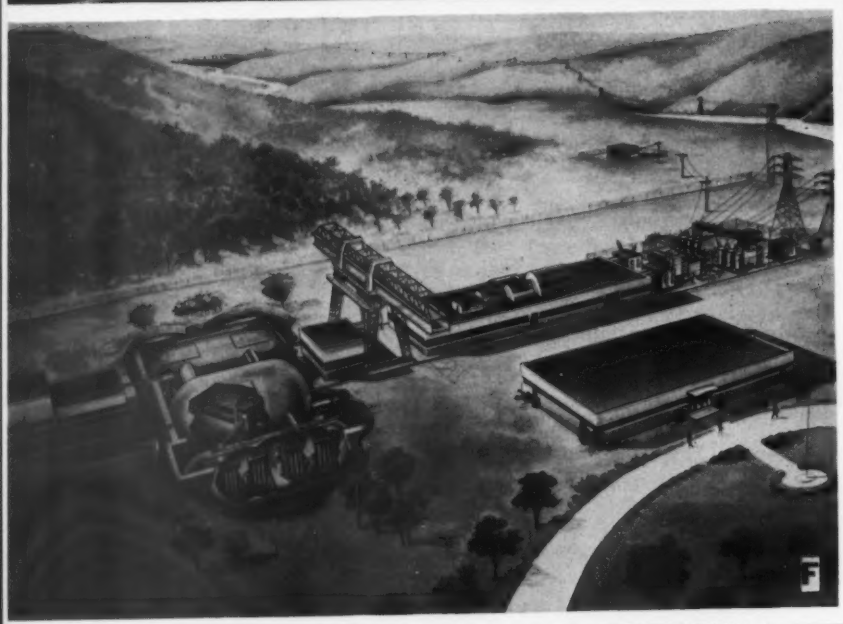
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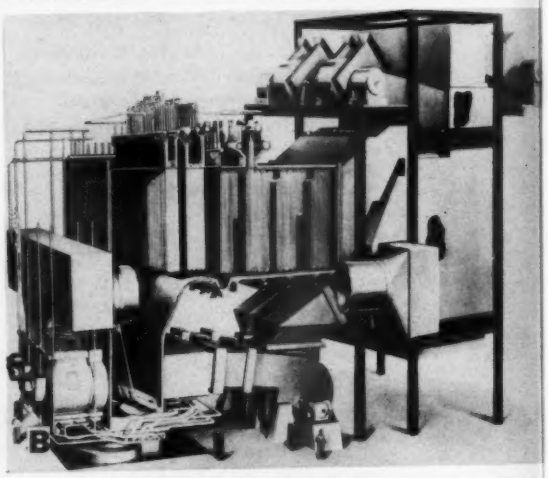
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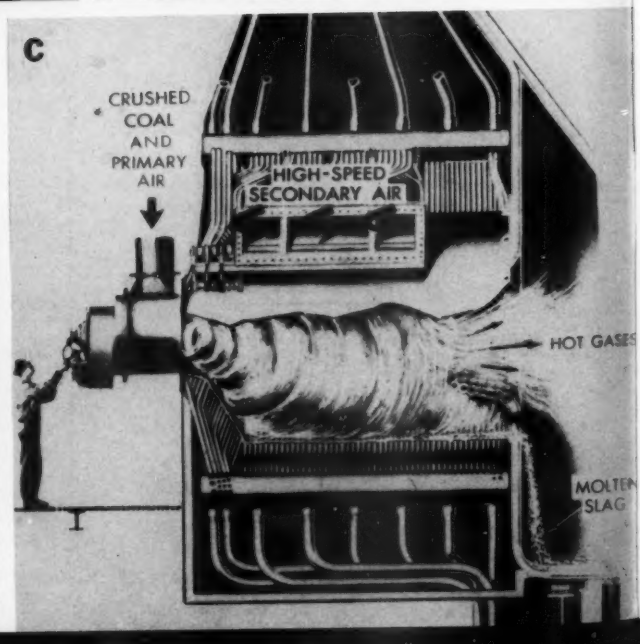
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CRUSHED COAL AND PRIMARY AIR
HIGH-SPEED SECONDARY AIR
HOT GASES
MOLTEN SLAG

ULTRAMODERN STEAM PLANTS FOR THE PACIFIC NORTHWEST POWER SYSTEM

FLOYD D. ROBBINS

Assistant Professor of Electrical Engineering

F. D. Robbins

"The Northwest Power Pool, which supplies power to this region, has at the present time little or no reserve capacity, so that even with stream flow exceeding that normally expected, at times it is necessary to drop some loads . . . In addition . . . a number of large potential users of power are waiting to sign contracts. . . .

"Present plans call for the construction of additional hydroelectric plants mostly on the Columbia River and its tributaries, but even if the proposal is kept on schedule or even accelerated, the power shortage will likely continue at least into 1954."[1]

These statements, made by the writer in *The Trend* of October, 1951, fit the power picture in the Pacific Northwest as aptly today, except that a prediction now may well be extended almost another decade. In fact, today the situation is even more critical. Upstream storage has lagged because the projects completed in the interim have been largely of the low or medium head-river flow type with little storage.

A graphic picture of the situation is given in Fig. 1. These curves were plotted from data based on continuous research on the subject at the University of Washington. The curve marked (1), a plot of the total installed and planned generating power in the area of the Northwest Power Pool, including the states of Washington, Oregon, Idaho, Montana, and part of Utah, takes into account every known existing installation and planned power project in this area down to and including those of 0.1 megawatt (100 kilowatts), regardless of type of ownership.[2,3] Values shown are name-plate ratings in megawatts. The curve branches at the year 1954. The upper dotted branch shows the predicted installation schedule as it would have been had the 1952 planning been followed.[4] The present situation indicates that resources now available to the Power Pool will be as shown on the lower branch (solid curve).

Power-load prediction curves, determined by several independent methods, are shown in Fig. 1 as curves (2) and (3).[5] Curve (2) shows the minimum amount of installed capacity to just meet predicted loads, with no margin and provided that the rate of load increase does not change. This could happen if prospective users of large blocks of power can be assured that their power needs will be met, even under the worst water conditions. Curve (3) shows the basic capacity needed to serve the predicted load, plus a small reserve. This reserve would probably be quickly absorbed as soon as available. The curves predict a power shortage of approximately 2000 megawatts in 1958 and, in 1962, of between 2000 and 5000 megawatts. This estimate does not include about 500 megawatts of small steam plants now in operation but obsolescent and inefficient. The Western Group of the Northwest Power Pool, where most of the industrial and population increase will occur, will, of

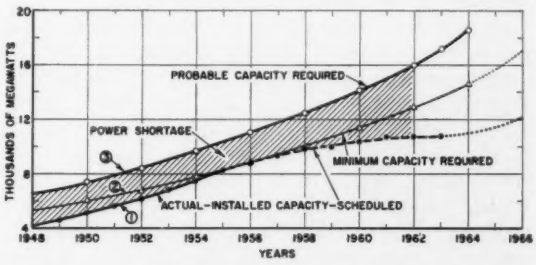

FIG. 1. PREDICTED LOAD AND INSTALLATION CURVES FOR THE PACIFIC NORTHWEST

LEGEND

PLATE I

A. Typical large-sized high-pressure reheat turbine. B. Supercritical pressure steam generator. C. Cutaway of cyclone furnace. D. Artist's view of Clifty Creek Power Station, Madison, Ind. E. Four turbine-generators of the Joppa, Ill., station. F. Preliminary artist's sketch of the nation's first atomic powered electric generating station under construction at Shippingport, Pa. *(Left to right)* Building for fuel handling, atomic reactor and heat exchangers, maintenance building and overhead crane, turbogenerator building, switchyard containing transformers and circuit breakers, and transmisson lines. *(Right foreground)* Shop and administrative facilities. The cutaway view shows that the atomic reactor and heat exchangers will be underground in concrete and steel structures.

Views A and E, *courtesy of* GENERAL ELECTRIC COMPANY; B, C, and D, BABCOCK & WILCOX COMPANY; and view F, WESTINGHOUSE ELECTRIC COMPANY.

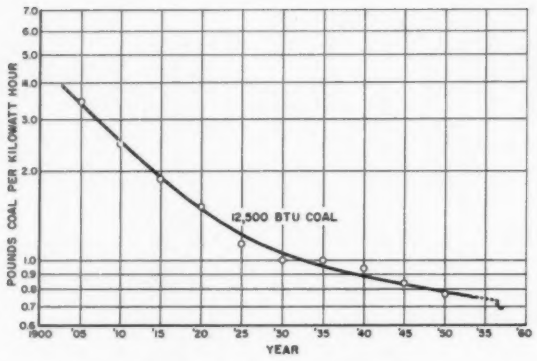

FIG. 2. U.S. STATION COAL RATE
Adapted from chart by permission of GENERAL ELECTRIC COMPANY

course, be the most seriously affected. The Bonneville Power Administration recently reported[6] as follows:

> After balancing foreseeable with presently scheduled generation we find that firm loads will exceed prime capabilities of West Group utilities by over 200 megawatts in 1961-62 and 800 megawatts by 1963-64. The potential 800 megawatt shortage does not include consideration of the existing 400-megawatt interruptible industrial load, steam displacement, or a large expansion of electrochemical or electrometallurgical industries.

If consideration is given to the interruptible 400 megawatts and to the 500 megawatts now furnished by obsolescent steam plants, a need of new generation in the Western Group alone of at least 1700 megawatts by 1963 can be safely predicted. The picture is even more gloomy if the possibility of two successive low water years is considered. The need, therefore, is urgent for additional generating capacity that can be constructed quickly and easily, and can be built and operated economically.

As the writer pointed out in 1951, the steam plant has a very definite advantage in ease and speed of construction. It can furnish both dependable peaking capacity during flood time and dependable energy supply during low water, thus allowing hydro plants to save sufficient water to carry the peak load. The steam plant, which can be situated close to load and transportation centers and is not subject to high transmission costs and line failures, can also conveniently serve base loads. Moreover, a modern steam plant can be built and put on the line in about 1½ years, thus giving fast relief.

On this basis, steam plants can be utilized starting in September and running through until late May. Recent research and development have lowered the capital cost and raised the efficiency of the steam plant so that it is now economically competitive with hydro.

This report will present some recent developments in the design of steam plants, especially of the high-pressure, high-temperature type.

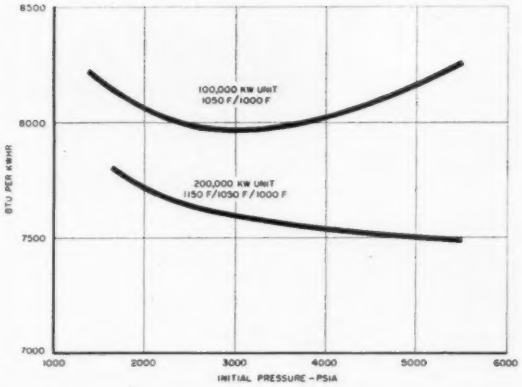

FIG. 3. THERMAL EFFICIENCY GAINS WITH INCREASED SIZE OF UNIT
Courtesy, GENERAL ELECTRIC COMPANY

As a modern example, take the Ridgeland Station[7,8] of the Commonwealth Edison Company of Chicago. Operating at 1900 psi, 1050° F, with 1000° F steam in 150-Mw turbines, from 1,100,000-lb-per-hour, cyclone-fired boilers using coal at $5.89 per ton, Ridgeland has an official power-production record of 3.29 mills per killowatthour.[9]

The curve in Fig. 2 shows how cooperative research and development have steadily increased the efficiency of plants so that 0.74 lb of coal will produce a kilowatthour in the best 1955 steam station, whereas it took 3.6 lb to do the job in the early 1900's.[10] On the basis of coal having 12,500 Btu per pound, this represents a heat rate of 9250 Btu per kilowatthour. This rate is expected to be reduced to 8500 Btu, or 0.68 lb of coal, when two superpressure plants now under construction are installed.[11,12,13]

It is still more startling to consider the equivalent heat rates if we refer to some of the earliest steam plants.[14]

The first practical steam engine, that of Thomas Savery (1699), which, of course, actually had no generator, would have had an equivalent heat rate of 2,000,000 Btu per kilowatthour.

The Edison Pearl Street Station (1882), using reciprocating engines, was the first central station built for the prime purpose of generating power. Its 55-kw unit would have taken 12 lb of the 12,500-Btu coal to produce a kilowatthour[14] as compared to the 0.85 lb taken by the Ridgeland high-pressure plant of today, which has a heat rate of 10,688 Btu per kilowatthour.

If we now project this progress into the future, the theoretical limit set by the Carnot cycle with 2500° F combustion temperature would more than halve Ridgeland's record to 4100 Btu and, with nuclear fission temperature of 10^6 degrees F, would effect a further reduction to 3413 Btu per kilowatthour.[14]

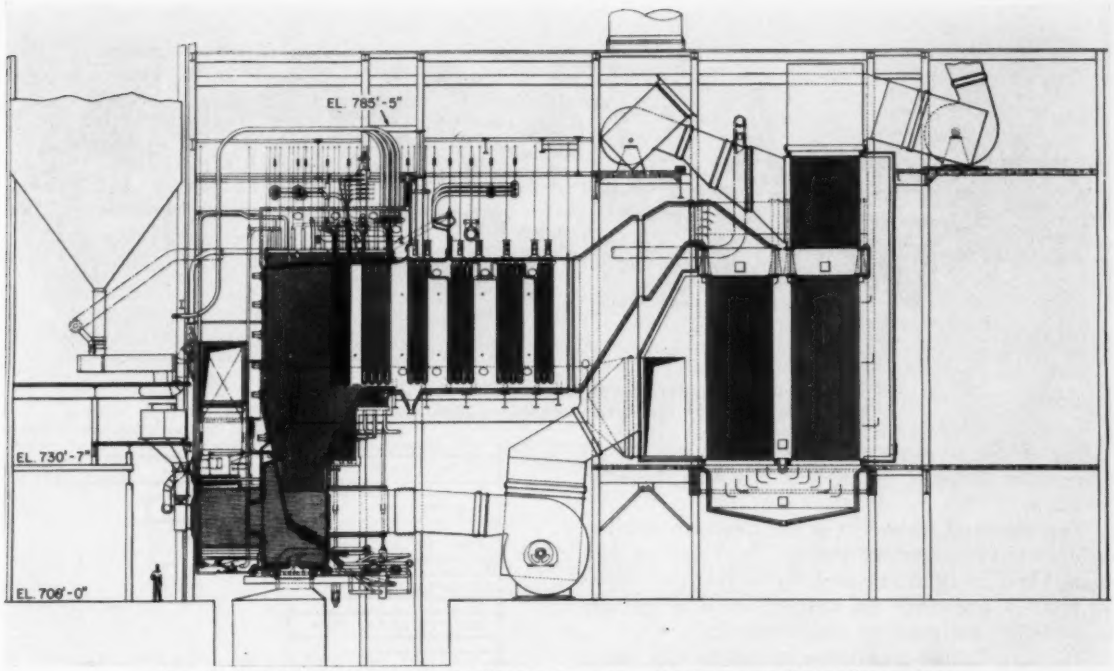

FIG. 4. SIDE ELEVATION OF PHILO PLANT SUPERCRITICAL PRESSURE STEAM GENERATOR
Courtesy, BABCOCK & WILCOX COMPANY

What are the design factors making possible a decrease in unit cost of power from steam plants in the face of a steadily increasing price index?

The first reheat boiler in the U. S. was designed and installed by Babcock & Wilcox, engineers for the Philo Station of the Ohio Power Company, in 1923 to serve a 40-Mw turbogenerator. The design pressure was 650 psi and the initial temperature, 750° F. This unit is of special interest since it will be mentioned later in connection with the new universal pressure boiler and turbine.

In the early thirties, a number of central steam power stations were built using the idea of resuperheat. Progress with this idea was impeded because plants using the regenerative cycle at higher temperature could match the thermal efficiency of the reheat plants at less cost. Pressure in these stations was on the 600- to 1200-psi level. In 1937, the Twin Branch Station of the Indiana Electric Company went into operation at 2300-psig throttle, with superheating to 940° F and resuperheat to 900° F.[15] This new record pressure was established with an open pass boiler. Rowand, in 1947, suggested that research and development based on customer needs, in which the trend was toward higher pressures, higher temperatures, and larger sizes in boiler equipment, should precede design.[16] In 1948, Harris and White demonstrated conclusively the thermal advantages of using high-temperature, high-pressure steam and the reheat cycle,[17] and, at the same time, Parker demonstrated that high-pressure, high-speed turbines using the reheat cycle were feasible to build in large sizes.[18] Plate I-A shows a typical large-sized turbine-generator unit located at Waukegan, Ill. It is rated 121 Mw, 1800 psig, 1000° F/1000° F. All these developments led to the conclusion that temperatures and reheat, when combined with high pressures, yield better thermal efficiencies in larger units. The thermal efficiency gains shown in Fig. 3 with a 100-Mw unit, 1050° F steam temperature and a 1000° F reheat, are seen to reach a maximum at approximately 3000 psia. A 200-Mw unit, using 1150° F steam temperature, one reheat at 1050° F, and a second reheat at 1000° F, shows continuous thermal efficiency gain up to at least 5500 psia. At present 5000 psia and 1150° F seem to be the maximum conditions obtainable with metals now available. However, the following predictions have been made:

(1) With the larger turbine capacities expected in the future and assuming that initial and reheat temperatures will continue increasing at their historic rate of 12° F per year, the best station, by 1975, would have steam temperatures 1400° F/1300° F/1250° F. With such temperatures it appears that 10,000-psi steam pressure is as high as would be desirable.[19]

(2) Unit sizes of turbines will probably be above 250 Mw.[20]

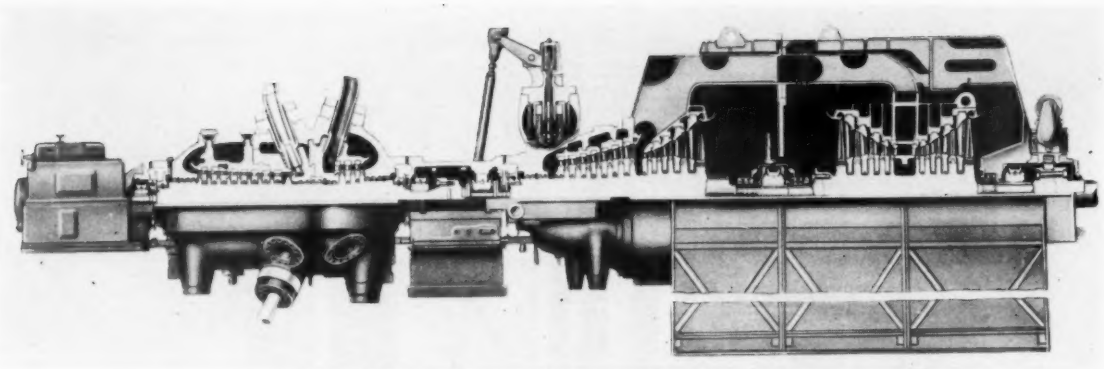

FIG. 5. QUARTER SECTION OF REHEAT STEAM TURBINE
(3600 rpm; rated 145 Mw, steam conditions, 2300 psig 1100°F/1050° F)
Courtesy, GENERAL ELECTRIC COMPANY

(3) Boiler research and development will always have to be ahead of turbine design if progress is to be made.[21]

Experience of the writer in the Research and Development Laboratory of Babcock & Wilcox in Alliance, Ohio, in 1952, revealed that at that time levels of 1600° F and 6000° psi were regarded as not only possible,[22,23] but practical and economical.

The world's first superpressure unit is now under construction at the Philo Station of the Ohio Power Company. The new unit is rated 125-Mw, 4500-psi, with temperatures 1150° F/1050° F/1000° F, and with a steam generator (boiler) rating of 675,000 lb of steam per hour. This new unit will have an over-all thermal efficiency of 40 per cent, with an over-all plant heat rate of 8500 Btu per kilowatthour.[11] At Philo station in the same building and on the existing foundation of the original 40-Mw unit mentioned earlier, the new superpressure boiler with a turbo-generator operating at 4500 psi and 1150° F/1050° F/1000° F, will produce 125 Mw in the same space, using 45 per cent less fuel per kilowatthour than the original plant.[24] Figure 4 shows a cross section of the cyclone-fired, supercritical pressure steam generator designed for the project. (See also Plate I-B.) Figure 5 shows a cutaway of a steam turbine differing only slightly in design from the Philo unit.

The chart shown in Fig. 6 gives a good graphic picture of the net heat rates at various combinations of temperatures and pressures discussed above.

Proposed construction of another superpressure station was recently announced by the Philadelphia Electric Co.[18] The new unit will have a rating of 275 Mw, 5000 psi, 1200° F/1150° F/1150° F, served by a steam generator rated at 1,540,000 lb of steam per hour. The predicted over-all heat rate of the plant will be 8400 Btu per kilowatthour.

It will be noted that the method of firing of the Philo steam generator is not by the conventional pulverized fuel system but by the new and revolutionary

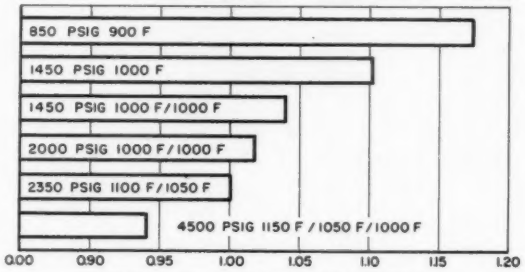

FIG. 6. GAINS IN EFFICIENCY WITH INCREASED PRESSURE AND TEMPERATURE, AND REHEAT
Adapted from chart by permission of GENERAL ELECTRIC COMPANY

cyclone furnace. The writer spent the summer of 1952 in the Research and Development Laboratory of the Babcock & Wilcox Company in Alliance, Ohio, on a research project with two objectives: (1) to study the development of the cyclone burner, and (2) to determine the feasibility of using the cyclone burner for burning a low-grade bituminous coal of the same type as is found in the Pacific Northwest. This coal is not suitable for ordinary commercial use and no large scale market will open up except to serve large steam plants.[25] Moreover, the coal could not be burned successfully in any existing burner. Numerous tests were made on a wide variety of coals and a comprehensive report was prepared.[26] Excerpts from that report are given here, with the permission of Babcock & Wilcox.

> The cyclone furnace has been aptly described as the most significant development in the burning of coal since the advent of pulverized coal firing.[27] As such it has already revolutionized the performance standards expected of modern large steam electric generating stations. . . .
>
> The advent of the cyclone furnace was formally announced to the engineering world in December of 1946. . . . Some of the following points brought out in the original article[28] are of special interest.

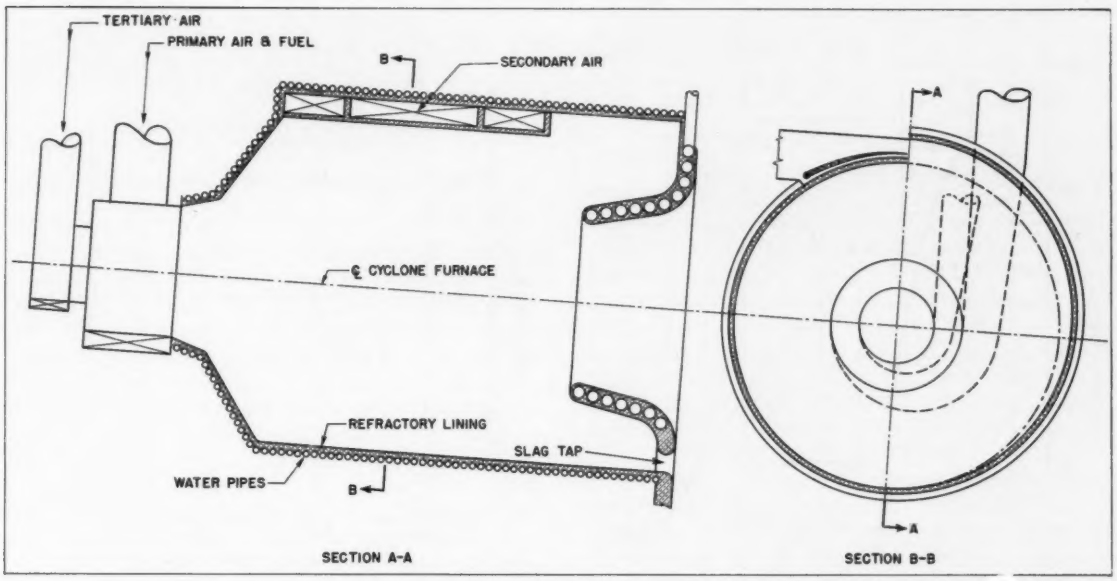

FIG. 7. CROSS-SECTION VIEWS OF CYCLONE FURNACE

"Some years ago the Babcock & Wilcox Company approached the problem of utilizing advantageously the generally considered undesirable characteristics of the ash in coal. It was felt that if the ash liberated from the coal upon combustion could be kept where it belonged, namely in the furnace, one could not only effectively and efficiently use poorer grades of coal but at the same time largely eliminate the slag-cleaning problem so prevalent with both stoker and pulverized coal firing. Furthermore, by increasing the rate of burning of the coal the size of the furnaces necessary for a given capacity could be reduced. This would result in a reduction in the cost of making steam which would be attributable to decreased capital expenditure for the equipment involved, as well as savings in its operation and maintenance. These savings would result from the following:

"1. A very considerable reduction in the amount of slag deposited on the heat absorbing surfaces of the unit: a corresponding reduction in the existing large item of cost of labor for keeping such surfaces clean, and the possibility of minimizing boiler outages due to slag.

2. Reduction in the size of the furnace and the entire boiler unit.

3. Simplification of equipment with attendant reduction in cost of removal of ash from combustion gases to avoid objectionable atmospheric pollution.

4. If instead of pulverizing coal, it could be crushed to some larger size, much less work on the coal would be required for burning which would involve savings due to the substitution of a crusher in place of pulverizers with some corresponding decrease in equipment and maintenance costs.

5. The considerable reduction in the amount of ash in the combustion gases, with resultant lack of necessity for lancing, etc., would permit pressure operation of the unit with possible elimination of induced draft fans with resultant savings in installation costs and corresponding reduction in cost of operation and maintenance.

6. With the accomplishment of the foregoing savings there would be a reduction in size of building required to house the entire unit, with corresponding reduction in building costs."

To achieve these results it was decided to employ the principles of a cyclone [which can best be described by reference to Fig. 7 and Plate I-C]. If crushed coal is admitted tangentially to a cylindrical burner in a stream of air, at a sufficiently high velocity, the particles of coal will be thrown to the surface of the cylinder and will be carried in the stream along the wall of the cylinder in the form of an increasing pitch helix until the energy of the entering stream of air has been dissipated. If, in addition to the primary air, sufficient secondary air for the combustion of the coal is admitted in a path parallel to the primary air and coal and at a correspondingly high velocity, and if at the same time the temperature is sufficiently high to promote and maintain combustion, the volatile matter in the coal will first be distilled and burned; then the remaining carbon will be burned and finally the ash will be left. Provided the fusing temperature of the ash is lower than the temperature obtained on combustion, it will be in a molten state as slag. This resulting slag, due to the energy in the stream of products of combustion will be in contact with the surface of the cyclone furnace so that it becomes entirely coated with molten slag.

By inclining the axis of the cylindrical chamber the molten slag will drain toward its low point from which it can be removed continuously. As this molten-slag surface of the furnace is established, further crushed coal, when admitted with the primary air, will be thrown to the surface of the cylinder by the energy of the conveying air and will be caught by the slag. The movement of the slag on the surface of the furnace due to its viscosity, is very much less than the velocity of the entering air, and this provides an intense scrubbing action of the high-velocity air on the combustible of the coal particles entrapped and moving with the slower moving film of molten slag, with resulting extremely high combustion rates. . . .

Another advantage of the cyclone furnace is its ability to burn a wide variety of coals including those of low rank and

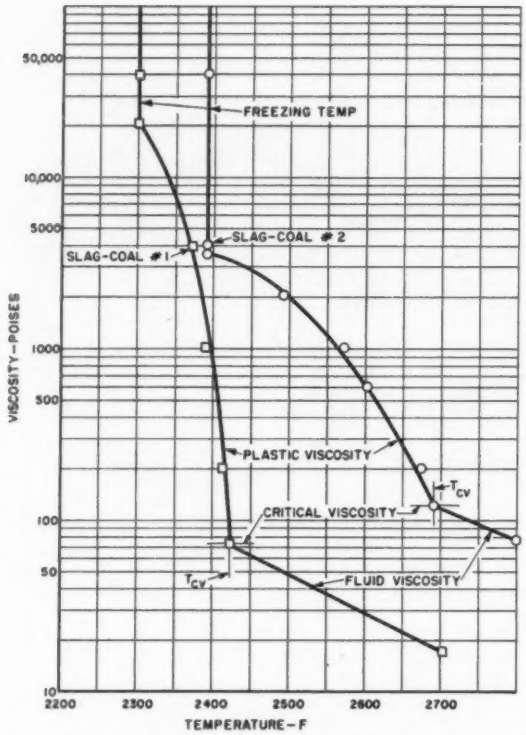

FIG. 8. RESULTS OF TESTS ON SLAG OF TWO TYPICAL LOW-GRADE COALS
Courtesy, BABCOCK & WILCOX COMPANY

high ash content. This point is highly important since fuel cost is the predominant cost entering into the unit cost of electric power. The ability to burn these low rank coals may well be the deciding factor in determining the feasibility of steam plants in some regions like the Pacific Northwest and Western Canada, where immense deposits of low rank coal await development. . . .[29] [The state of Washington alone, has 62 billion tons of low-grade bituminous and subbituminous coal.[30, 31]]

Results of tests on slag of two typical coals with the characteristics of Washington coals, are shown on the curves of Fig. 8. Slag (1) can be cooled slowly from any high temperature where it exists as a liquid, there being a gradual increase in liquid viscosity until the critical viscosity of 66 poises is reached, when further cooling causes separation of crystals and there is a transition to plastic flow. This transition occurs at approximately 2420° F. Further cooling results in a rapid increase in plastic viscosity until at 2300° F the slag suddenly freezes to an apparently solid mass and the bob can no longer be rotated. Slag (2), of different composition, behaves similarly, but its critical viscosity is 120 poises and the critical viscosity temperature is 2690° F; it freezes to a solid at 2390° F.

This shows that the slag from Washington coals lies within the limits of the cyclone and that these coals will burn successfully in this burner. The curves of Fig. 8 may be used to construct a much easier chart to read, such as Fig. 9. Here any coal which has the viscosity and ash-softening-temperature

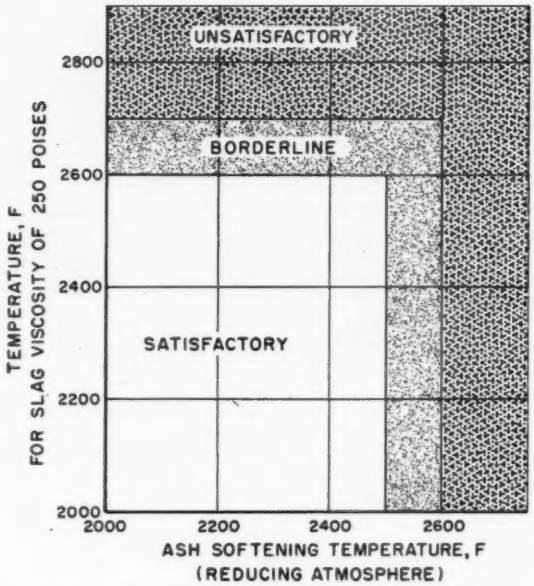

FIG. 9. SUITABILATY TESTS OF COALS FOR USE IN CYCLONE FURNACES
Courtesy, BABCOCK & WILCOX COMPANY

characteristics to place it in the inner square will burn successfully in the cyclone. With a few minor exceptions all Washington coals are in this category.

A plant using Washington coal would have a steam generator like that shown in Fig. 4, fired by cyclone burners. The best combination obtainable would be a 5000-psi, 1200° F/1150° F/1150° F double-reheat-cycle steam generator serving a 200-Mw, 3600-rpm turbogenerator. The predicted heat rate on such a combination would be 8450 Btu per kilowatthour. The Puget Sound region should have one plant of at least two such units, and the Vancouver region another similar plant.

These plants would resemble the one shown in Plate I-D, the new Clifty Creek plant which is delivering energy to the Atomic Energy Commission uranium diffusion plant at Portsmouth, Ohio.[32]. The unit size here is the ideal 200-Mw. This plant took two years from drawing board to operation. The outside of such a station might be as shown in Plate I-E, where outside construction has been used to cut capital cost. This plant, at Joppa, Illinois, is furnishing power to the Atomic Energy Commission plant at Paducah, Kentucky.

The recently described test run of the *Nautilus,* and the declaration of Commander Wilkinson that the range of the submarine is no longer governed by the operation of its power plant but by the amount of food it can carry and the physical endurance of its crew,[33] has opened up to the popular view a whole new world

(Continued on page 26)

BEHAVIOUR OF CELLULOSES IN SODIUM HYDROXIDE SOLUTIONS*

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Introduction

The nature and behaviour of assemblies of cellulose molecules, such as fibers, fibrils, and crystallites, can be studied by observing the changes resulting from treatments with aqueous solutions of alkalis and many investigations of this kind have been carried out.[1] It is known that native cellulose exists in part in a lattice usually designated as Cellulose I, and that by treatment with sodium hydroxide solution the cellulose may become mercerized and converted into another lattice known as Cellulose II. It has also been found[2] that a higher concentration of sodium hydroxide in solution is required to produce the mercerizing effect on cotton cellulose than on purified wood cellulose. Jørgensen and Ribi[3] have shown that this difference is not attributable to differences in magnitude or distribution of molecular weight of the two celluloses, and have suggested that it was caused by differences in the structure of cellulose crystallites or micelles. Rånby's investigations[4] led him to the conclusion that "—native wood cellulose has a larger active surface than cotton cellulose—," and that "—the start of the phase transition is related mainly to the reacting structural elements, i.e. the micelles and the micelle strings, while the completion can be hindered by the packing of the elements, i.e. the fiber structure."

In the present investigation, the action of sodium hydroxide on celluloses has been further studied using both X-ray diffraction and moisture sorption methods, in order to try to secure a better understanding of the mechanism of mercerization and of the reason for the differences in behaviour shown by wood and cotton and other celluloses. Rånby's observation[5] that the increase in water sorption starts at a somewhat lower sodium hydroxide concentration than the phase transition indicated by the X-rays has been of special interest.

Experimental.

Cellulose samples: Three samples, designated as K, L, and S, were studied. These had been prepared under conditions which did not give rise to mercerization. Some characteristics of the samples are as follows: *Cellulose K;* bleached kraft cellulose from Southern hardwoods, 93.4% alpha cellulose, 3.3% beta cellulose, and 3.3% gamma cellulose. *Cellulose L;* cellulose from cotton linters, 99.2% alpha cellulose, 0.6% beta cellulose, and 0.2% gamma cellulose. *Cellulose S;* bleached sulfite cellulose from Western Hemlock wood, 96.7% alpha cellulose, 1.6% beta cellulose, and 1.7% gamma cellulose.

Treating Procedure: Five grams of a cellulose was weighed out after having been "disintegrated" in an air dry condition in a Koerner hammer mill. Two hundred ml of the appropriate sodium hydroxide treating solution was prepared by mixing freshly distilled water in the necessary proportions with a stock fifty weight percent sodium hydroxide solution and then determining by titration the final alkali concentration which ranged between 1.0 and 15.6 weight percent NaOH. The cellulose and sodium hydroxide solution were placed together in a 600 ml Pyrex beaker, covered, and allowed to stand for three hours in an ice bath with treating bath temperature ranging from 0 to 3° C. Distilled water (300 ml) was then added and the suspension was filtered through a copper screen as soon as possible. The cellulose was washed thoroughly with distilled water, with a 2% solution of acetic acid, and finally with distilled water until neutral. Water was removed by the suction of a water aspirator pump, by gently squeezing the "filter cake" between the fingertips, and then by drying for 36 hours at room temperature in vacuum over anhydrous calcium chloride.

X-Ray Diffraction Measurements: An X-ray unit equipped with a scanning Geiger counter was used for the diffraction. The counter was connected to an automatic recorder which traced the diffraction diagram as the counter scanned within the desired angles of diffraction. The X-ray beam was produced by a copper tube with emission current and voltage stabilized at 20 mA and 40 kv, respectively. After passing through the slit system, the incident beam struck the cellulose sample and was diffracted. The diffracted beam was filtered by a nickel foil which passed only the CuK_{alpha} radiation ($\lambda = 1.54$ Å) through a new slit system and onto the Geiger counter.

Cellulose samples were exposed to laboratory atmosphere for 48 hours to secure air-dry equilibriation. Two different slices were prepared from each

* Extracted from a thesis submitted by Ole Anker-Rasch in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering, University of Washington, and reproduced by permission from *Norsk Skogindustri,* 10/54, the journal of the Pulp and Paper Industry of Norway.

† Mr. Rasch was a recipient during 1952-1953 of a Scholarship from the Research Council of the Pulp and Paper Industry of Norway, and also of a Fulbright Travel Grant from the United States Government.

"filter cake" and an X-ray diagram of each was obtained. The cellulose was contained in a flat aluminium holder with a rectangular hole 20 x 10 x 2 mm. The filter cake slices were cut exactly to fit this hole in the holder. The fit was sufficiently tight to keep the sample in place without other support, so that the X-ray beam passed only through the cellulose and there was no absorption by another material.

No corrections have been made for loss of material during swelling. Since both impurities and low molecular weight celluloses are dissolved, Rånby concluded that any such correction would be of doubtful validity.[4] Moreover, such dissolving should bring about an increase in the sharpness of the diffraction patterns as sodium hydroxide concentration in the treating solution increased, but a decrease in sharpness of the patterns is found experimentally in this study.

The effects of orientation of fibers during filtration have also been considered. By studying diffraction patterns on cellulose samples obtained by slicing the "filter cakes" in different directions, a slight orientation effect was found to exist. However experiments were carried out and it was shown[6] that the magnitude of the effect could easily be kept substantially constant, and this was done. A true powder diagram was preferred but it was found impossible to obtain such a diagram with satisfactory reproducibility.

Water Vapor Sorption Measurements: Aliquots of the treated cellulose samples were kept for 3 days in a room maintained at 23° C at 50% relative humidity. Thereafter the samples were weighed, were completely dried at 105° C for 4 hours or more in an oven with forced air circulation, and then were weighed again, and the extent of water sorption was calculated.

Results and Discussion.

The type of experimental results obtained are exemplified by the diffraction patterns shown in Figure 1 for sulfite pulp as: (A) native cellulose, (B) a mixture of native and mercerized cellulose, (C) mercerized cellulose, and (D) the "blank" line obtained by scanning the counter while the sample holder was empty.

The diffracted beam intensity attributed to the cellulose sample was obtained by subtracting the blank from the total observed intensity and this corrected beam intensity was always used in the calculations. Thus the corrected diffracted beam intensities averaged at 15.4 degrees between the angles 14.4 to 16.4 degrees, and also at 18.4 degrees taken between 18.0 and 18.8 degrees have been used to establish the ratio,

$$R_0 = \frac{I_{15.4}}{I_{15.4} + I_{18.4}} \qquad (1)$$

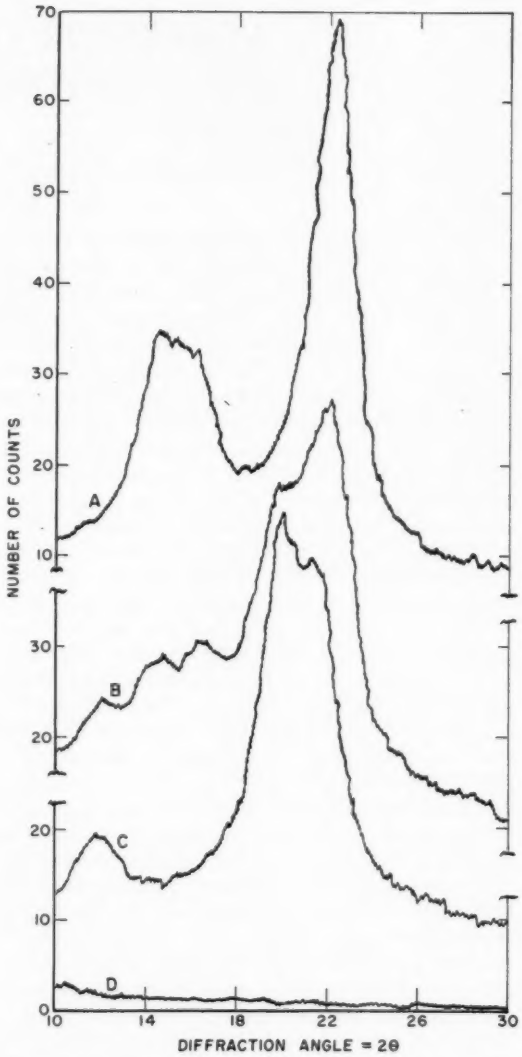

Figure 1. ***Example X-ray diffraction patterns for sulfite cellulose:*** **(A) Native, (B) Partly mercerized, (C) Mercerized, (D) Blank.**

A high value of R_0 indicates a high intensity of the reflections from the 101 and $10\bar{1}$ planes in the native lattice and this may in turn be interpreted as a high degree of order in the existing assembly of cellulose chains. A low value will then mean a low degree of order or a low "crystallinity," but, of course, values of R_0 lose significance as reflections from Cellulose II appear.

In Figure 2, R_0 is plotted against the concentration of sodium hydroxide present in the treating solution. Each value shown is the mean from two independent experiments and on the average the duplicate values

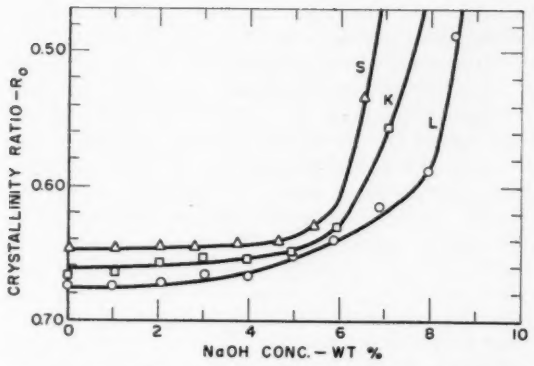

Figure 2. *Crystallinity ratio of celluloses treated with various concentrations of sodum hydroxide:* (S) sulfite cellulose, (K) kraft cellulose, (L) cotton cellulose

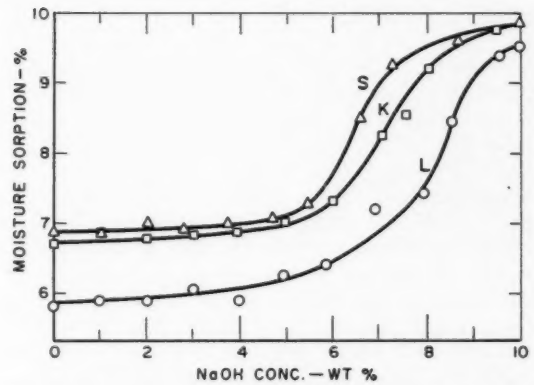

Figure 3. *Moisture sorption of cellulose treated with various concentrations of sodium hydroxide:* (S) sulfite cellulose, (K) kraft cellulose, (L) cotton cellulose.

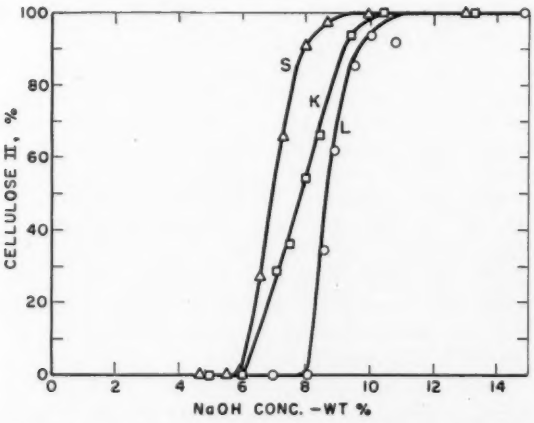

Figure 4. *Extent of conversion from cellulose I to II of celluloses treated with various concentrations of sodium hydroxde:* (S) sulfite cellulose, (K) kraft cellulose, (L) cotton cellulose.

agreed with each other to the extent of 0.0026 express at R_0 units. It is seen that the "degree of crystallinity" appears to be greatest for cotton cellulose, less for kraft cellulose and least for sulfite cellulose. A similar order for "crystallinity" in the native cellulose is indicated by the moisture sorption curves which are shown in Figure 3, although the quantitative positioning of the kraft cellulose behaviour between the other two celluloses is somewhat different depending upon whether the diffraction or the moisture sorption results are considered.

However the "degree of crystallinity" seems to be steadily decreased as the concentration of sodium hydroxide in the swelling solution is increased as is indicated by the diffraction and moisture sorption results given in Figures 2 and 3. These curves for each investigated cellulose have nearly identical shapes up to the sodium hydroxide concentrations at which phase transitions begin according to the results shown in Figure 4.

The diffraction pattern of Cellulose I is well known[3] and has been associated with the lattice structure proposed by Meyer, Mark, and Misch. The diffraction pattern of mercerized cellulose or Cellulose II is also known and has been associated with a different lattice structure.[3] Reflections from the 101 planes of these lattices are known to occur at angles over about 14.2 to 15.0 or at 14.6 degrees for Cellulose I, and over about 11.6 to 12.4 or at 12.0 degrees for Cellulose II. Using the corrected intensity of the diffraction beams at these angles, there has been evaluated a ratio, R_x

$$R_x = \frac{2I_{12.0}}{2I_{12.0} + I_{14.6}} \qquad (2)$$

from which the percent Cellulose II was estimated by use of the relation,

$$\text{Percent Cellulose II} = \left(\frac{R_x - R_I}{R_{II} - R_I} \right) 100 \qquad (3)$$

where R_I and R_{II} represent the values of R_x just before phase transition begins and just after phase transition ends respectively. The percentages of Cellulose II may be only roughly accurate in an absolute sense when computed in this way, but it is believed that they are nearly correct in relative sense because Rånby approximately verified the method using known mixtures of Cellulose I and Cellulose II.[4] In present experiments the R_x values on a sample were reproduced to the extent of 0.0063 R_x units on the average. The percentages of Cellulose II in the various samples were calculated by use of Equation 3 and the results are plotted in Figure 4 which shows how the proportion of Cellulose II increases with increase in concentration of sodium hydroxide in the treating solutions.

For all the celluloses now investigated it is found that Cellulose II appears at concentrations of sodium hydroxide rather considerably higher than those at which substantial decrease in "crystallinity" (Figure 2) or increase in water sorption (Figure 3) becomes evident. Rånby previously showed that this relationship existed for a bacterial cellulose, and he explained it by assuming "that a partial transition into an X-ray amorphous prestate, for instance at the surface of some micelle strings, takes place before the reaction goes deeper into the strings."[5]

It thus appears probable that sodium hydroxide molecules or sodium ions are sorbed in the surface of the Cellulose I crystallites to an increasing degree as the concentration of sodium hydroxide is increased up to the level at which phase transition begins. Washing out of this sodium hydroxide leaves behind the influenced molecules perhaps in part to recrystallize as Cellulose I and in part to remain in a disordered or amorphous state so that a decreased "crystallinity" and increased water sorption may be observed.

With further increased sodium hydroxide concentration, Cellulose I is in part converted so that a Cellulose II lattice appears when the sodium hydroxide is washed out. Since the conversion of Cellulose I to II at room temperature occurs irreversibly,[7] and since the formation of Cellulose II from Soda Cellulose I is reversible,[1] then the transition of Cellulose I to Soda Cellulose I must be irreversible. However the fact that partial conversion of Cellulose I to Soda Cellulose I occurs in a few minutes at a particular sodium hydroxide concentration whereas not much further change occurs over a much longer additional time is believed by the writers to indicate that some kind of equilibrium is involved in the conversion of Cellulose I to Soda Cellulose I.

Perhaps the penetration or strain of the Cellulose I lattice occurs in a potentially reversible manner until there is finally reached a critical state of strain[8] which we represent as Cellulose I*. When the sodium hydroxide concentration exceeds that corresponding to the Cellulose I* state, the sodium hydroxide particles penetrate the lattice which then goes irreversibly over to Soda Cellulose I,[9] and then reversibly to the more stable Cellulose II when alkali is removed from the system: Cellulose I + NaOH $\rightleftarrows$ Cellulose I* $\rightarrow$ Soda Cellulose I $\rightleftarrows$ Cellulose II + NaOH (4)

This mechanism for the mercerization process gives rise to the suggestion that the lateral order in the Cellulose II lattice will be lower than in the original Cellulose I because of the disordering of the chains produced by the first reaction in Equation 4. Such a conclusion is in agreement with published "crystallinity" data.[10,11]

The Cellulose I crystalline regions appear to exist in native cellulose as rather discrete crystallites or "strings" and Rånby[5] has reported different numerical values for average widths and also width distributions for wood, cotton, bacterial and animal celluloses. If these strings are assumed to be right circular cylinders of width or diameter D, of density ρ, and with surface area per gram A, then it is apparent that $A = 4/\rho D$ and thus the surface free energy per gram of cellulose becomes larger as size of the strings decreases. Perhaps it is this surface free energy as determined by the size and shape of a particular crystallite and its lattice imperfections which may determine its critical degree of strain and thus the concentration at which the sodium hydroxide becomes able to enter the lattice and bring about phase transition to Soda Cellulose I. The work of attempting quantitative formulation of these relationships is going forward in this laboratory.

Thus if a large moisture sorption indicates a large average effective crystallite surface area for a cellulose, then from the values obtained in present work and also by Rånby, it is expected that half-completed phase transformation would occur for sulfite cellulose at the lowest sodium hydroxide concentration and for kraft and cotton cellulose at higher concentrations and this is what is found by the experiments. Since Rånby obtained number average string widths of 77, 88, 97 and 110 Å for wood, cotton, bacterial and animal celluloses, respectively, then phase transformation should take place at lowest concentration for the wood cellulose and at higher concentrations for the other celluloses, and this is observed experimentally. However the fact that conversion of Rånby's wood cellulose occurs nearly to completion at a sodium hydroxide concentration at which a cotton cellulose of about the same string diameter apparently would not be converted,[5] may indicate differences in the quality of crystallite surfaces, i.e., the presence in the wood cellulose of a more roughly shaped surface and/or of more lattice imperfections.

The occurrence of the phase transformation over a range in concentrations of sodium hydroxide may arise as a result of the existence of the observed range in crystallite string widths or shapes[5] and thus of the corresponding range in effective areas and free energies per crystallite. On this basis, phase transition over a relatively narrow range of sodium hydroxide concentration may indicate that distribution of crystallite effective areas is relatively narrow in the sulfite and cotton celluloses and somewhat broader in the kraft celluloses studied in the present investigation with results given in Figure 4.

Both the average free energy per crystallite or average effective crystallite area, and the distribution of these free energies—as indicated in Figure 4—are supposed to be important characteristics for a chemical grade cellulose since such properties will influence

most chemical reactions with cellulose.

The writers are grateful to Dr. James I. Mueller of the University of Washington for permission to use the X-ray equipment; to Mr. Donald Kotzerke of the University of Washington for aid in calculations; and to the Skogbrukets og Skogindustriens Forskningsforening of Norway, to the United States Government and to the University of Washington for scholarship grants to one of us (O.A-R.).

Summary.

Cotton cellulose and sulfite and kraft wood celluloses have been treated with aqueous solutions ranging in concentration from zero to fifteen percent sodium hydroxide. After washing out the alkali, the celluloses were examined by use of the methods of X-ray diffraction and water sorption. In confirmation of Rånby's observation, it is found that cellulose "crystallinity" decreases and water sorption increases as the concentration of sodium hydroxide used for the treating is increased up to that at which phase transition begins. Transition of Cellulose I to II proceeds with further increased sodium hydroxide concentration, first for sulfite and kraft celluloses, and then for cotton cellulose. To explain these differences it is suggested that the conversion of Cellulose I to Soda Cellulose I occurs in two steps, the first of which is reversible and may permit Soda Cellulose I formation at a relatively low sodium hydroxide concentration when crystallite strings are of small width or are imperfect and thus have a large effective area and a large surface energy per unit mass. On this basis, and from Rånby's measurements, it appears that crystallites with the largest effective area exist in the sulfite cellulose with smaller effective areas in the kraft and still smaller in cotton cellulose. Also a relatively narrow distribution in crystallite effective areas is found in the cotton and sulfite celluloses with a broader distribution in the kraft cellulose.

Seattle, Washington, 8 April 1954.

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Let's Look at Engineering Education

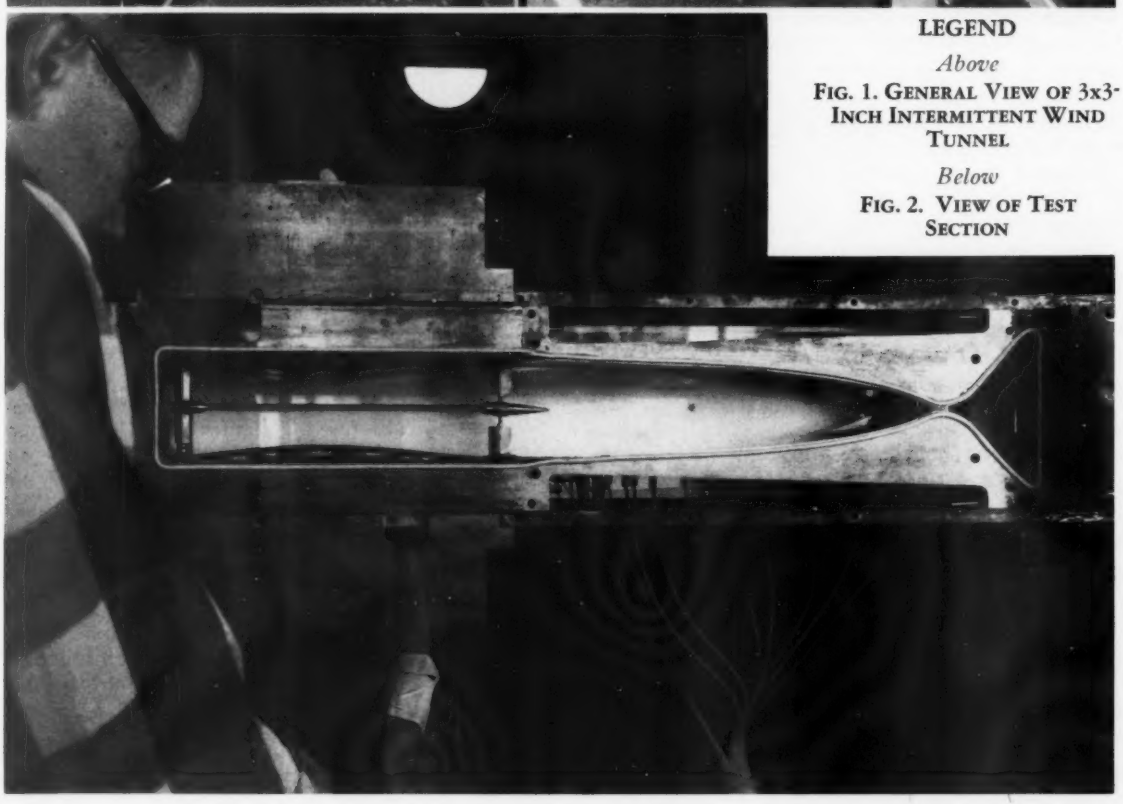
THOMAS H. CAMPBELL

(Continued from page 1)

These are, of course, only a few examples, but they serve to illustrate the many currents and eddies — and probably a few backwaters — of present thought regarding engineering education in this country.

But, realistically, if one will take the time to stand back from the multitude of vigorous questions and proposals, and look at our engineering education in the perspective of both time and location, he might see the current stirrings in a different way. He will find that during the past century education has never been static, but always seething in its concept of objectives and methods, as it is now. Each generation of teachers has learned its own lessons in its own way. He will note anew the great diversity of method now practised even in this country: the project method, the problem method, the lecture and laboratory method, the "fundamental" approach and the "practical" approach. Especially he may see that each generation, each country, each school and each method has somehow produced its share of competent, successful professional engineers. Furthermore, he may be impressed at the percentage of engineers successfully practicing in fields other than those in which they took their degrees, at the number of graduate engineers who have gone into management or business, and at the number of successful practicing engineers who received their formal training in areas other than engineering.

One may conclude that it is not possible to make rigid pronouncements as to how engineering should be taught, but it would be erroneous to infer that any hit-and-miss sort of training is adequate. The point may be that it is not so important what philosophy is adopted so long as it is believed in by the faculty, coordinated throughout the entire curriculum, and taught by competent — even inspired — teachers who know that they are taking raw but living material and helping fashion it into a finished product able to rise to a great future need.



LEGEND

Above

FIG. 1. GENERAL VIEW OF 3x3-INCH INTERMITTENT WIND TUNNEL

Below

FIG. 2. VIEW OF TEST SECTION

THE INTERMITTENT SUPERSONIC WIND TUNNEL

R. E. STREET
Professor of Aeronautical Engineering

R. E Street

Since the article, "The Low-Density Supersonic Wind Tunnel," by G. E. Ledbetter* was published, the two small wind tunnels described therein have been completed, and for several years have been in active use at the University of Washington, serving primarily as equipment for graduate students doing experimental theses in supersonic flow. Most of these projects have been sponsored by the Engineering Experiment Station.

The present report will be devoted to the 3 by 3-in. intermittent wind tunnel, known as tunnel No. 1. The 1 by 2-in. continuously operating tunnel (No. 2) will be discussed in a future issue of *The Trend*. These two tunnels comprise the total present facilities of the Supersonics Laboratory. Mr. Ledbetter's article was concerned almost entirely with Tunnel No. 2, the only one operating at that time. However, even the physical set-up of that tunnel has changed so much since then, that his description is no longer completely applicable.

Tunnel No. 1 is shown in Fig. 1. The large tank on the right is one of two surplus altitude chambers connected so as to give a total volume of 1575 cu ft. These tanks can be evacuated to an absolute pressure of 2 mm of Hg (0.25 psi), or less, by a 25-hp Kinney DVD 141418 oil-seal rotary vacuum pump, in less than half an hour. Opening the large Nordstrom valve (between the test section and the tank in the photograph) through a 90° turn gives a run of about 30 seconds. This time is sufficient for taking schlieren photographs, either by spark or longer exposures of $\frac{1}{5}$ to $\frac{1}{150}$ of a second, or for photographing the manometer board. This manometer board gives simultaneous readings of both pressure distributions over models and wall static pressures. The pipe on the left acts as a settling chamber for the air before it expands through the nozzle blocks. Another quick-opening Nordstrom valve (not shown) at the upstream end of this entrance pipe was added recently. By opening the downstream valve, with the upstream valve closed, it is possible to evacuate the test section before making a run. This feature has turned out to be very useful since it enables the area around the test section to be checked for leaks as well as facilitating the starting of the tunnel, especially when the Mach 5 nozzle is mounted in the tunnel.

There are two sets of two-dimensional nozzle blocks made of mild-steel carefully cut and ground to the profiles which, according to the theory of characteristics, would give Mach numbers of 3 and 5. (The theoretical design allowed for the growth of the boundary layer.) Thus, in Fig. 1 are seen the Mach 5 nozzle blocks with a total pressure tube in the test section, followed by a two-dimensional supersonic diffuser the area of which can be adjusted by the motor-cam arrangement also shown in Fig. 1. The double-pass schlieren system uses a G.E. AH-6 mercury vapor lamp, one 8-ft focal length, 6-in. diameter parabolic mirror, and one plane 6-in. mirror. Light source, mirrors, and camera are all hung from a rigid platform suspended from the ceiling and free to roll in a horizontal direction. This feature, together with the plate glass sides of the tunnel, enables the flow to be observed all the way from the first throat, through the nozzle, test section, and diffuser (Fig. 1). A close-up of the test section is shown in Fig. 2.

Until very recently the 3 by 3-in. tunnel has been operated with the nozzle blocks designed to give a Mach number of 3($M = 3$). This means that the air, initially at rest in the room, will accelerate through the nozzle until at the test section the speed of the air is three times the speed at which sound travels in the same air. Since the speed of sound is proportional to the square root of the absolute temperature, and the temperature of the air drops rapidly with the expansion of the air, the speed of sound is much lower in the test section than in the room. However, in the aerodynamics of supersonic flow it is the local Mach number that determines the air forces acting upon bodies in the flow.

At $M = 3$, the low temperature of the air (theoretically about 190° absolute, or -270° F) causes no real difficulty, since on the walls of the tunnel or on models and probes the temperature rises to about 90 per cent of room temperature. The only factor of concern is that any moisture in the room air will condense at this low temperature and give rise to a spurious type of shock wave called the "condensation shock." With the Mach 3 nozzle, this difficulty has been satisfactorily avoided by causing the air to pass through

* See *The Trend in Engineering*, Vol. 1, No. 1 (Dec., 1948).

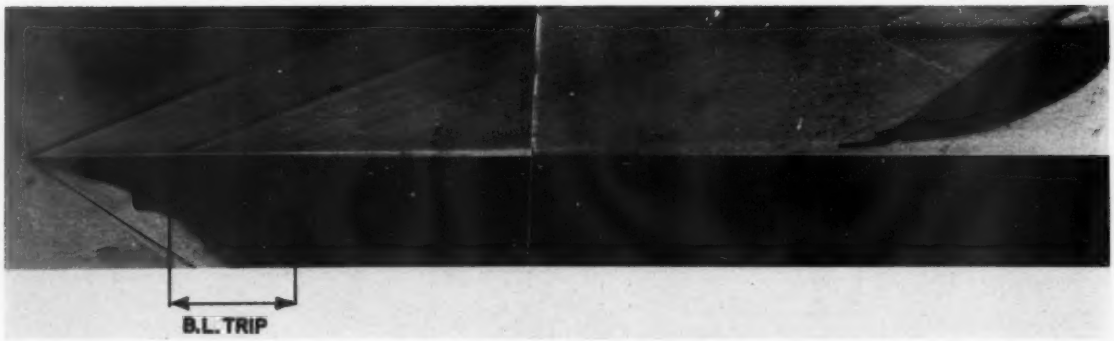


FIG. 3. SCHLIEREN PHOTOGRAPH OF BOUNDARY LAYER ON FLAT PLATE

several hundred pounds of activated alumina spread out in two beds inside a sheet metal box* underneath the platform on which the nozzle and test section are located. The activated alumina absorbs most of the moisture in the air prior to expansion to $M = 3$.

Measurement of the Mach number in the test section has been performed repeatedly over the past four or five years by students working for the M.S. degree and by students in laboratory courses. At first the mean of such measurements was 2.96 to 2.97 but has risen to 3.00 in recent measurements. This change is due to the fact that whenever the nozzle blocks are removed they cannot be replaced exactly as they were. On the other hand, the fact that the design value of 3.00 can be attained is an excellent confirmation of the theory used in making the original design calculations. Similarly, a total head survey across the test section in both horizontal and vertical directions has shown that the flow is uniform and constant except for about 0.15 in. of boundary layer on each wall. The test section dimensions are 3.1 by 3.3 in. Thus an area of 3.0 by 2.8 in. is available for aerodynamic tests.

Although the boundary layer on the wall is turbulent in the test section, it is not known whether the center portion of the flow is of high turbulence level or not, but it is certainly too high to classify this tunnel as a low-turbulence wind tunnel. Mr. C. L. Shih, in his 1951 thesis, obtained laminar boundary layers on the walls of the test section by reducing the stagnation pressure (or total head) to 40 per cent of room pressure. He did this by putting a throttling valve ahead of the intake pipe to the nozzle block. At 40 per cent total pressure the Mach number drops to 2.44, and at 16 per cent total pressure it becomes 2.00. The reason for the decrease in Mach number is that the growth in boundary layer thickness cuts down the effective area of the tunnel test section, and a smaller area means lower Mach number when the throat area is fixed. The reduction in pressure lowers the Reynolds number of the flow, but also makes it harder to start the tunnel and leads to difficulty with leaks in the test section and diffuser.

An investigation now under way as an Experiment Station project has as its object to determine precisely what the effects of pressure ratio, temperature, and humidity are upon the running time, and will also include the Reynolds numbers available. As mentioned previously, 30 seconds running time is usually available with the 1575-cu ft vacuum chamber exhausted by the Kinney DVD rotary pump. Whether this can be increased by changing air pressure and temperature, and how low a Reynolds number can be produced, are questions which remain to be answered.

Another project, which is partially completed, is the construction of a small strain gage balance to measure lift, drag, and moment of small three-dimensional models of wings, bodies, etc. This is believed to be the smallest such balance with external sensing elements ever to be designed, and of course it is impossible at present to predict its success or usefulness.

One thesis project, also carried out in this tunnel was that of D. R. Lane, completed in 1953.* He built a flat-plate model with probe to measure boundary-layer profiles from 3.84 in. to 7.84 in. downstream of the leading edge which had a roughness trip to ensure a turbulent boundary layer. Figure 3 shows a schlieren picture of the flow over the flat plate. Besides the shock waves off the leading edge of the plate, the trip, and the probes, the growth of the thick boundary layer is seen in this figure. Mr. Lane's results, while limited to a narrow range of Reynolds number around a mean value of one million, do agree with other experiments in checking the so-called "extended" Frankl and Voishel theory of the turbulent boundary layer at supersonic speeds.

* Not shown in Figure 1.

* See *The Trend in Engineering*, Vol. 5, No. 3 (July, 1953), for abstract.

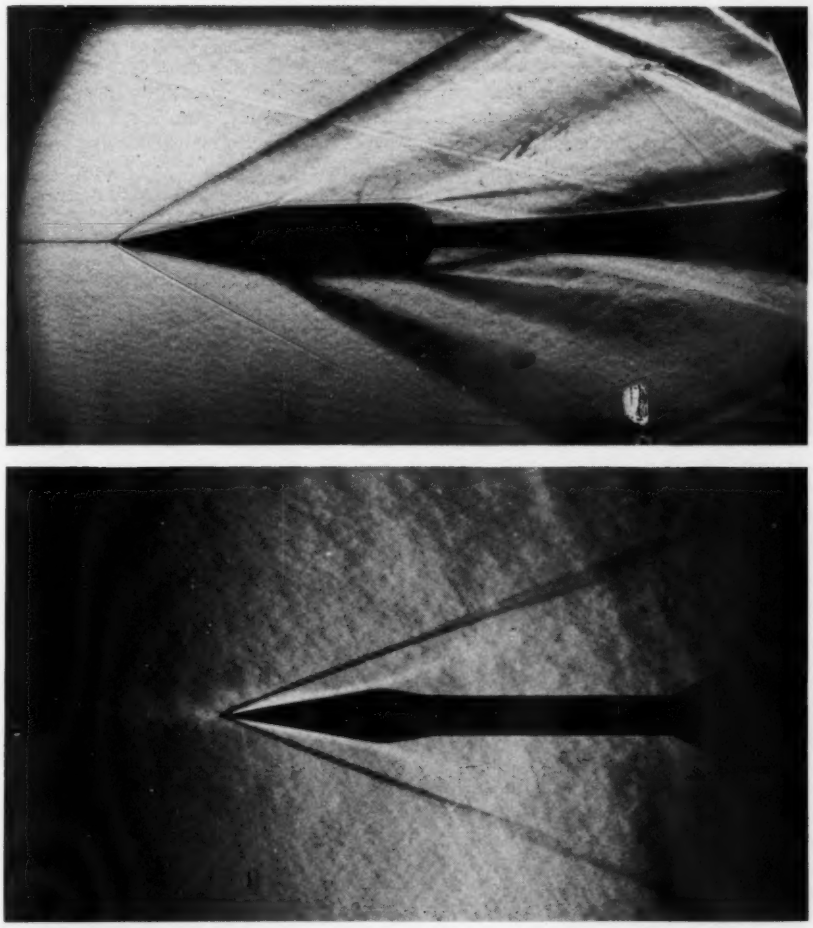


FIG. 4. *Above*: SCHLIEREN OF SINGLE WEDGE AT M=3. *Below*: DOUBLE WEDGE AT M=5

A 3-in. round nozzle, originally planned, was never constructed, but two-dimensional nozzle blocks designed to produce a Mach number of 5 were constructed. The most interesting work this past year has been with these nozzle blocks, now mounted in the wind tunnel. They are shown in Figs. 1 and 2, together with a conical type of total head probe for measuring the stagnation pressure in the center of the test section. Figure 4 is a schlieren photograph of the shock waves on two 20° wedges at $M = 3$ and $M = 5$, respectively. The shock wave is fainter at the higher Mach number because of the much lower density in the test section, and dies out before reaching the wall because of a considerably thicker boundary layer.

The results of the data so far collected with these new nozzle blocks are still few and quite sketchy. No surveys across the test section have been made, because Mach numbers as measured by shock-wave angle, wall static pressure, and total head are too divergent to give the true Mach number. Measurement of shock-wave angle gives $M = 4.7$; the wall static pressure is not consistent on repeated runs although it gives an indicated $M = 4.4$, while the total pressure measurement leads to $M = 5.4$. Such a discrepancy in measurements could be due to many factors. At present the most obvious one is that the air is not sufficiently dry. A dew-point indicator has been acquired and shows that the dew point is only 10° F. Hence the dryer is being fitted with thermocouples, and an attempt will be made to reactivate the alumina at higher temperatures than used heretofore. Also, since some room air has been leaking into the test section through cracks in the walls, better methods of sealing are necessary to ensure that only dry air reaches the test section.

If any discrepancy remains in Mach number readings after the air is dried (dew point of -20° F or

lower) and all leaks are sealed, its cause will be the condensation of the air itself. That is, at $M = 5$, since the static temperature may reach 90° absolute or -370° F, liquid drops of oxygen or nitrogen may form. Fortunately, the air is at this low temperature for so short a time that condensation possibly will not occur. If it does, about the only solution is to preheat the room air until condensation stops.

Since pressures in the test section at $M = 5$ are of the order of 2 mm of mercury, when air is expanded from 1 atmosphere or 760 mm of mercury, the sealing of the test section as well as the rest of the channel has been much more of a problem than at $M = 3$. Also, the mercury manometers used in the past are not precise or consistent in readings, except for total pressure measurement. A portable Stokes vacuum gauge of the McLeod type has been found most satisfactory in obtaining the wall static pressure of the test section.

Although wind tunnels of this size, and particularly those of intermittent flow type, are now very common in this country, and larger tunnels have taken over most of the problems in basic and applied research, there are not many operating in the Mach number range between 4 and 5. It is expected then, that once the present difficulties are overcome, the 3 by 3-in. supersonic tunnel may be useful in extending research on certain fundamental problems such as boundary layer, shock waves, and temperature profiles up to the low hypersonic range ($M = 5$ or more). Another useful purpose, which will never be outdated, is the introduction of both senior and graduate students in Aeronautical Engineering to the problems and techniques of supersonic flow measurement.

A Research Personnel Problem

NO ONE CAN PRETEND to be a ball player, but, unfortunately, it is possible—often unwittingly—to masquerade as a research scientist and perhaps no area in the technical field offers greater sanctuary for incompetence than does research.

"At first this may seem paradoxical because of the inherent difficulty of the subject matter and the unquestioned excellence of the people who are leaders in this profession. In the area of research that may reasonably be described as basic, perhaps only 10% of the total effort leads directly to a positive successful conclusion. Nine-tenths of the effort, although perhaps conducted on an equally high level, yields negative results. In one sense this is not wasted effort since it has at least resolved the question of the need for exploration in the particular area. However, it is difficult to distinguish in many cases between incompetence and inherent impossibility of the solution.

"A fast growing group of those not well fitted for the task of research is made up of people, usually with excellent academic background, who have become so engrossed in the tools of their trade that they have lost all contact with reality. In this group we might find one who, describing himself as an applied mathematician, could prove, for example, that a bicycle cannot be ridden. When called to his attention that experience was contrary to his conclusion, he is not the least impressed. It is only the beauty and symmetry of his symbolism that is important. He has taken flight from reality. He is a scientific schizophrenic, happy in the world of his own making. Sometimes, in defense of these people, examples are recalled from history which show that great benefits were derived from the apparently aimless meanderings of some earlier genius. This is true. But research is a luxury and it must be purchased with great care. It would be no more logical for an organization to invest a large proportion of its funds in research because of the possibility of great returns than it would for a business man to invest most of his funds in a sweepstakes race merely because it has paid the highest returns on a given investment.

"Complicating the problem still further is the existence of another group who have learned that the actions and sounds of competent research people can be readily imitated. They propound ideas and write papers that serve mainly to distract their more competent associates from more useful pursuits. This is strikingly analogous to the example of two locomotives hauling a train of cars. One locomotive may be completely inoperative yet it will look exactly like its mate and perhaps even make the same noises; yet it is riding dead-head, contributing nothing to the effort. It is really impossible from a superficial examination to determine which one is genuine in either case. An erroneous statement made most casually by one such individual may occupy hours of time to disprove. It is a real tribute to the technical stability of this country that it has been able to survive the avalanche of pseudo-scientific papers and reports inspired in many cases by frantic efforts of some for publicity."—**"The Shortage of Technical Personnel," by W. J. Moreland, *Journal of Engineering Education*, November, 1954.**

STRENGTH OF TRUSSED COLUMNS

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Recent interest in the strength of trussed columns has motivated a theoretical study of this problem. Although it was known that bracing a column by trussing (or staying) increases its strength, the degree to which this effect occurs was less evident. Results of our theoretical investigation not only confirmed this conjecture, but indicated that the load-carrying capacity of a column, in some cases, can be nearly *quadrupled* by trussing it.

Before proceeding further, it is perhaps desirable to define the term, "trussed column." Consider a column, with round or hinged ends, with a "spider," or diaphragm, normal to the axis of the column, situated somewhere between the ends. If bracing wires, or guy-wires, are attached to the ends of the column and held away from the column axis by the "spider" we will have a stayed or trussed column (Fig. 1). The trussing wires, or guy-wires, may have initial tension, be snug, or they may be slack. Trussed columns belong to the class of columns having a lateral support—in this case, at the "spider." This support is provided by the trussing wires, the "spider," and the column itself, and under certain conditions may be yielding or non-yielding. A non-yielding support behaves as a rigid support but need not have an infinitely large stiffness or spring modulus. The yielding support is analogous to an elastic lateral support where the reaction is proportional to the displacement. In the former case, the column buckles into two half-sine curves, and in the latter into a single curve with lateral displacement at the intermediate support, or into two half-sine curves with a lateral displacement of the intermediate support. The column with the non-yielding trussing system has the greater load-carrying capacity. The column with the yielding lateral support, however, does support loads, whose magnitudes depend on the deflection of the column.

Constructing the Model

The model is a seamless steel tube with 0.625-in. outside, and 0.5-in. inside diameters, and approximately 71-in. length between pinned supports. Trussing was accomplished by a four-way "spider" and 0.041-in. diameter steel piano wires. (See Fig. 1.) The angle between the column axis and trussing wires was changed by shifting inward or outward small pulleys located in the "spider" arms. These pulleys also served the purpose of equalizing the tensions in the trussing wires each side of the "spider." Initial tensions in the trussing wires were first measured sonically by comparing the tone of vibration of the trussing wires with the tone of vibration of a wire of the same length and known tension. This method, with an SR-4 resistance gage mounted on the column for a check, proved quite reliable. However, as there was no way of measuring the tension in the trussing wires as loading was applied, and because the junior author insisted that he has no ear for music, it was decided to use strain-resistance gages in each trussing wire. These gages, which were designed by Professor Vasarhelyi, had a high degree of accuracy. They were mounted on thin brass strips, and were in series with the wire.

Constants and Properties of Model

The column cross section had the following properties: area = 0.0935 sq in.; moment of inertia about a diameter = 0.00387 in.^{4}; and corresponding radius of gyration = 0.2035 in. The slenderness ratio of the untrussed column was 349. The normal modulus of elasticity, E, was taken as 30×10^6 psi for the column, and 28.5×10^6 psi for the trussing wires. The first value was obtained by setting the Euler load equal to the experimental buckling load and solving for E, and the second was taken from the Tacoma Narrows Bridge model.* The diameter of the trussing wires was 0.041 in., and the cross-sectional area was 0.00132 sq in.

Procedure

In determining the strength of the experimental column, two parameters were varied, namely, the angle α between the column axis and the trussing wires, and the initial tension, T_0, in the trussing wires. Five values of angle α were used: 4° 40′, 5° 29′, 7° 57′, 10° 23′, and 12° 46′. The last three were greater than the so-called critical angle, and the first two were less than the critical angle. The critical angle is the line of demarcation between yielding and non-yielding lateral support. This angle varies with the initial tension in the trussing wires, and was theoretically estimated to approximate 6 degrees.

* Courtesy of Professor F. B. Farquharson, Director of the Engineering Experiment Station, University of Washington.

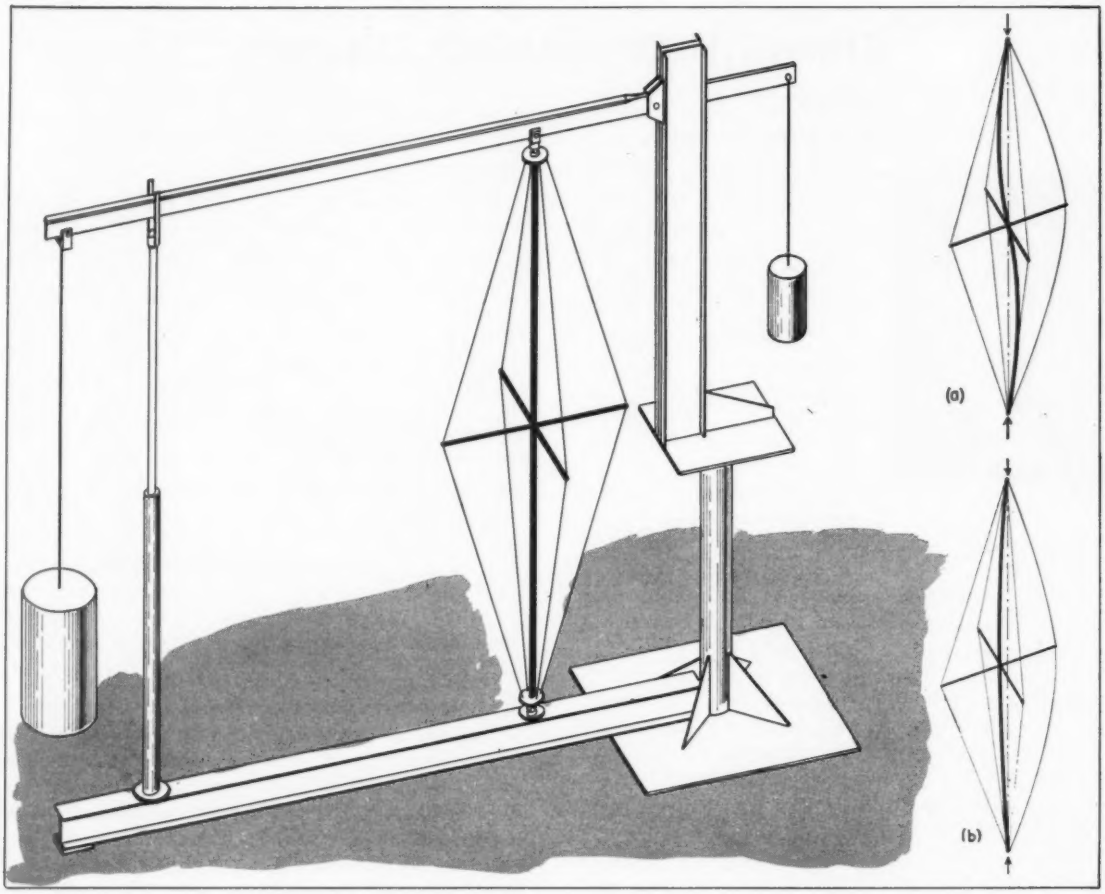


FIG. 1. LOADING FRAME WITH MODEL OF TRUSSED COLUMN

The range of values of T_o were as follows: 5, 10, 20, and 30 lb.

In Fig. 1-a, we show the deflected shape of the column axis for angle α of 12° 46′, with the trussing wire at the right, slack. The two wires perpendicular to the plane of buckling, are straight. Figure 1-b shows how the column axis was deformed before the double-reversed curve, shown in Fig. 1-a was obtained. Unfortunately, we do not have photographs of the actual curves obtained during the tests for all α angles used in the investigation.*

Buckling and bending was always in one plane because the pins at the ends of the column were perpendicular to this plane.

The experimental strength of the model column was determined in the following way. Angles α of the trussing wires were made equal for all four wires. Next, the initial tensions, T_o, in the wires were adjusted to the desired value and were made equal in all wires. This was done electronically from calibrations made in advance, using known tensions in the wires. Weights were then hung on the end of the loading arm until the critical load on the column was almost reached. The remaining increment of loading was applied by hand, using a spring balance. Since the column could support different loads depending on the amplitudes of the elastic curve, it was decided to use the following criteria to determine the strength of the column. For the case when the column axis was bent into two half-sine curves, buckling was easily obtained by a small alternating force superposed on the buckling load and applied to the loading arm. The column axis changed from the straight state to the reversed curve state quite perceptibly. For the case when the column axis was bent into a single half-sine curve with a lateral displacement, the strength of the column depended on the strength of

* The gages described on page 21 do not appear in the illustration.

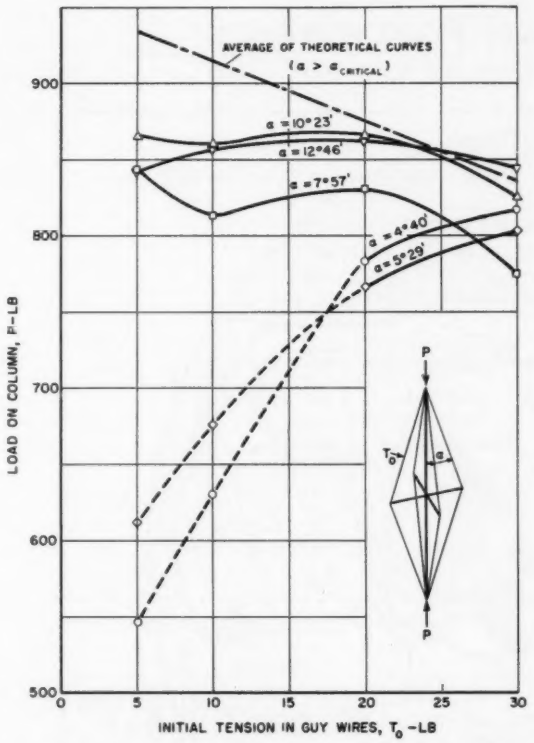


FIG. 2. STRENGTH OF COLUMN VS. INITIAL TENSION IN TRUSSING WIRES

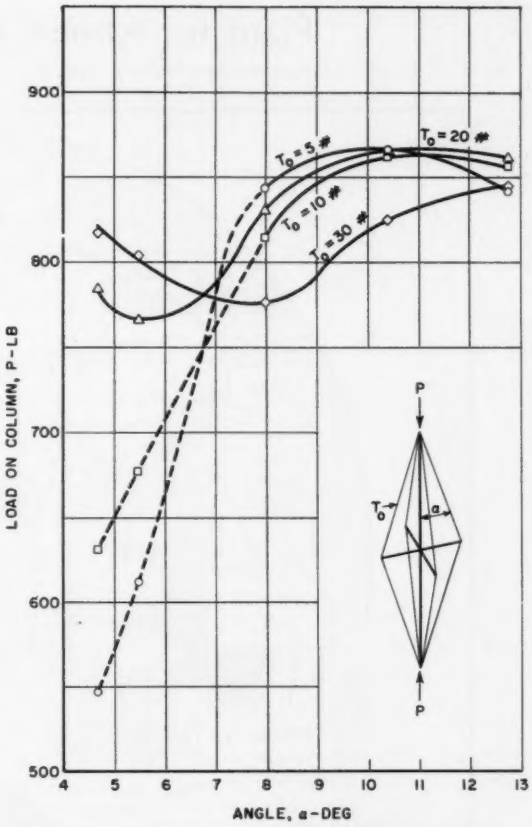


FIG. 3. STRENGTH OF COLUMN VS. ANGLE OF TRUSSING

the guy-wire located on the convex side of the elastic curve of the column. As a good practical procedure, it was decided to limit the stress in that guy-wire to 40,000 psi, this being the yield-point stress of structural steel. Larger stress in the guy-wire also increased the danger of failure in the brass strip on which the gage was mounted. Two such failures occurred during the test.

Results of Test

The results of this investigation are shown in the curves of Figs. 2 and 3. In Fig. 2 we have the strength of the column expressed by the load on the column, T_0, in pounds in the trussing wires, as abscissas. We see that the experimental strengths for angles α greater than the critical are, for practical purposes, independent of the angle. This seems to be true both for the experimental and theoretical (idealized) conditions. For angle α less than the critical, the experimental strength is much less. We do not show the theoretical curve for these cases because we believe the theory needs to be refined. The optimum experimental strength for angles greater than the critical angle, appears to be when T_0 is approximately 15 lb (stress of 11,500 psi), while for α less than the critical, it is when T_0 is 30 lb (stress of 23,000 psi). The P/A ratios for the column at the optimum points were 9,000 psi and 8,500 psi, respectively.

In the original tests made by the junior author for the case $\alpha = 4°40'$, the curve which started at P=500 lb for T_0=5 lb, reached P=625 lb at T_0 =24 lb, then dropped to P=600 lb at T_0=30 lb. Recent tests made on the same model by K. H. Jones and E. R. Anderson, students in Civil Engineering, indicate the load P tends toward 800 lb at T_0=30 lb. This difference in behavior we plan to investigate further.

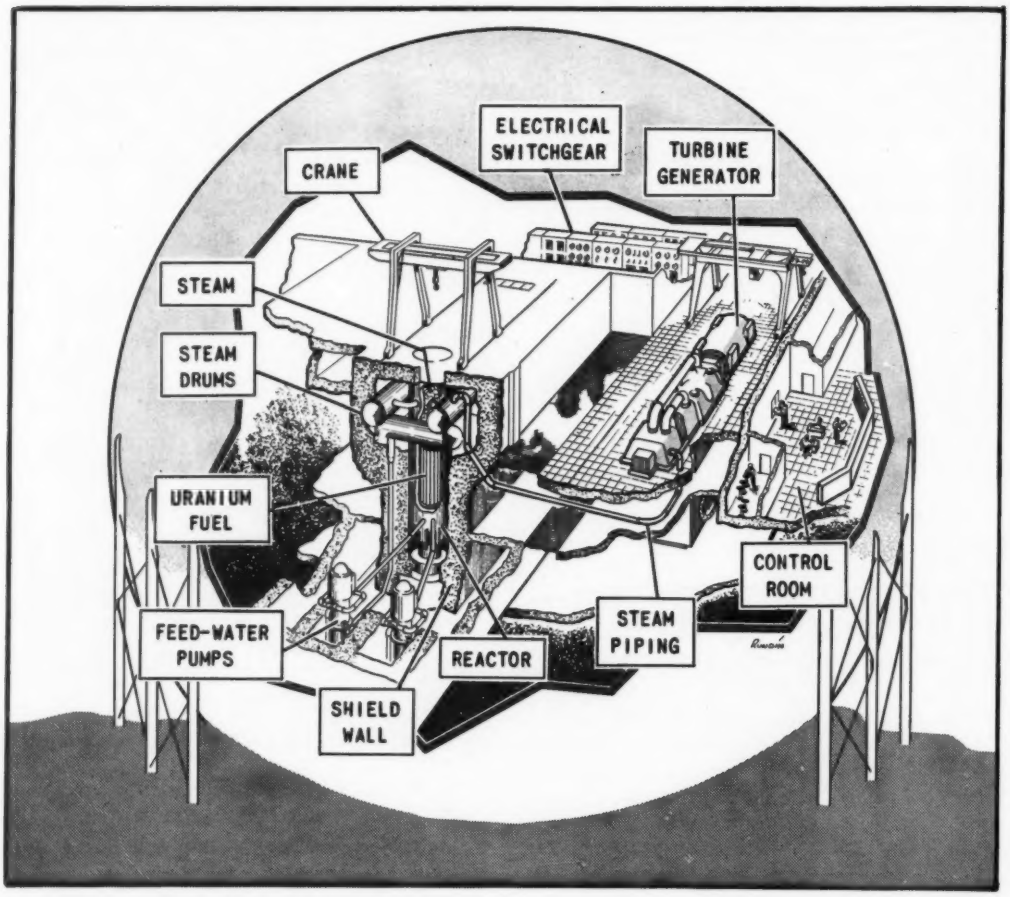
In Figs. 2 and 3, the dashed portions of the curves represent the strength of the column determined by the guy-wire with the greatest tension, when the stress in it was 40,000 psi. The column axis was in a single half-sine curve. This result is from the tests made by Jones and Anderson.

The Euler buckling load, without trussing wires, was 230 lb. Thus we see that for angles α greater than the critical, the column strength has been increased, on the average, 3.5 times. For the case when

(Continued on page 32)

Plans for Atomic Power Plant Advance

Reprinted by permission from *Engineering News-Record*, May 19, 1955, p. 27.



STEEL SPHERE about 200 ft in dia will enclose the reactor, turbine-generator and related equipment at the atomic power plant proposed for the Chicago area. *Courtesy,* ENGINEERING NEWS-RECORD

THE BOARDS OF DIRECTORS of the seven firms associated in Nuclear Power Group, Inc., have approved plans for construction of a $45-million nuclear power plant near Chicago.

Application to build the plant is before the Atomic Energy Commission. If it is approved, the plant will be built by General Electric Co. as prime contractor with Bechtel Corp. as engineer-constructor. It will be owned and operated by Commonwealth Edison Co.

The 180,000-kw plant will be the boiling water type. This type reactor was developed at Argonne National Laboratory. It differs from the full-scale pressurized water reactor being built at Shippingport, Pa., in which water is kept under enough pressure so that it does not boil in the reactor.

In the Chicago plant, water in the reactor will boil and form steam. The steam will flow through the pipes to the turbine and spin the generator as in a conventional power plant.

In the Shippingport plant, the water will flow through a heat exchanger where steam will be produced to activate the turbine. Elimination of the heat exchanger in the design of the Chicago plant will reduce its cost substantially.

The project will be financed entirely with private funds. Commonwealth Edison will pay $30 million of its cost and will spend an additional $4.5 million on transmission facilities to integrate the plant in its transmission system.

Other members of Nuclear Power Group, Inc., will pay $15 million into a new research corporation over a period of five years to supply the balance of the plant's cost.

Under this financing arrangement, it is estimated that the nuclear plant will produce electricity at a per kwh cost competitive with new coal-fired generating units in Edison's service area.

Nuclear Power Group, Inc., is composed of American Gas and Electric Service Corp., Bechtel Corp., Commonwealth Edison Co., Pacific Gas and Electric Co., Union Electric Co. of Missouri, Central Illinois Light Co., and Illinois Power Co.

Engineering Research Dividends

Recent theses submitted for advanced degrees from the College of Engineering, University of Washington, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station, University of Washington, Seattle 5.

KNUDSON, R. O., "Behavior of Box Beams Under Pure Bending." M. S. in Civil Engineering, 1954.

The problem of bending without shearing force of box beams was investigated on the basis of literature research and checks with models. A method was derived for computing stresses in such beams after buckling of the compression flange occurred. Plastic and aluminum sheet models were tested to destruction. The strains on the cross section were obtained by the use of SR-4 gages. It was found that, prior to the buckling of the compression cover plate, the stresses could be computed by the common flexure formula. After buckling of the compression cover plate the stresses can be computed by a modified form of the flexure formula. The values so obtained were in good agreement with the test results.

SASTRY, B. SRI RAMA., "X-Ray Diffraction Intensity Calculations of Alpha Quartz." M. S. in Ceramic Engineering, 1955.

The object of this project was to calculate the theoretical intensities of lines diffracted by the various *hkl* planes of alpha quartz. A great deal of detailed work has been accomplished in the past on obtaining the proper interplanar spacings for these planes and to obtain quite accurately the geometric dimensions of the unit cell. It has been noticed, however, that certain discrepancies appeared from time to time in otherwise consistent intensity values.

Intensity factors taken into account in this work were the Lorentz polarization factor, multiplicity factor, Debye-Waller temperature factor, atomic form factor, and structure factor. Calculations were made utilizing these for the following *h* scale values: 101, 100, 112, 121, 110, 102, 111, 200, 201, 003, 202, 103, 120, 113, 300, 122, 203, 301, 104, 302, 220, 123, 221, 114, 130, 131, 126. The calculated intensity obtained for the above were compared with those obtained experimentally for standard patterns of quartz.

Although most calculated values agreed with the experimental results, the intensities of the 101 and 100 planes which are of extreme importance in X-ray diffraction identification do not agree. Some time was spent in attempting to account for this, but nothing short of additional structure determination seemed to offer a solution. Work is being continued on this study to explain these discrepancies.

HSIEH, YUAN YU, "Structural Behavior of Beam and Column Joints in Reinforced Concrete Building Frames." M.S. in Civil Engineering, 1955.

Twenty plaster model frames were tested to destruction under six loading cases to determine some structural properties of building frames. The two-story, two-bay prototype frame was of reinforced concrete 10 feet in total height and 16 feet in total span length, and with beam gross cross-section 6 in. by 8 in., and column 6 in. by 6 in. The scale of model to frame was 1/6. The plaster used was "Hydrostone," one kind of gypsum-cement compounds made under new methods of manufacture which have developed in laboratory tests strength properties much higher than the values obtained previously for gypsum like plaster-of-paris. All specimens of the model frames, together with a number of control specimens, were cured in dry laboratory air. Test results show

(Continued on page 32)

Ultramodern Steam Plants for the Pacific Northwest Power System

(Continued from page 10)

of power. A brief review of the fundamental principles of electric power production from nuclear fission is in order before proceeding to a discussion of the economic place of nuclear steam plants in a power network.

Energy in conventional thermal plants comes largely from a chemical combination of carbon with oxygen to form carbon dioxide. Since the heat of formation of CO_2 is 94,000 calories per mole, it takes about ¼ pound of ordinary coal burning at 100 per cent efficiency to yield one kilowatthour of electrical energy. According to Einstein's equation, $E = mc^2$, one gram of matter, such as a cubic centimeter of water, contains an equivalent amount of energy of 9×10^{20} ergs, or $9 \times 10^{20} \times 2.778 \times 10^{-14} = 25{,}002 \times 10^6 = 25{,}002{,}000$ kwhr. Thus the atomic structure itself contains energy approximately 25 million times that of ¼ lb of coal, but energy available only if it can be released under controlled conditions. Engineers express the energy released by nuclear reactions in electron-volts, or millions of electron volts (Mev). When a neutron strikes a U^{235} nucleus, about 200 Mev of energy is released, or 3.2×10^{-11} watt-seconds. To release 1 kwhr of energy, therefore, would require the fission of 1.12×10^{17} atoms, or only 4.4×10^{-5} grams.

Uranium 235 has the property of producing a self-sustaining process or chain reaction. A device in which this takes place is called a breeder reactor. Unfortunately, only about $\frac{1}{140}$ of the natural metal, uranium, consists of U^{235}, the remainder being composed mainly of another isotope, U^{238}. Neutrons from U^{235} in pure ordinary uranium are unable to produce fission in U^{238} unless the uranium is arranged in a lattice of small lumps in the presence of another substance called a moderator. One such moderator is ordinary carbon. If fission is produced in natural uranium, the products are heat and additional neutrons. One of these neutrons is used to continue the reaction, the rest to convert the predominant and non-fissionable U^{238} into Pu^{239}. Plutonium, a man-made element not yet found in nature, is fissionable yet can be safely stored and can be used in atomic weapons, if necessary.

A power plant using natural uranium can produce heat and plutonium. The Pu^{239} not essential to military needs can be fed back as fuel for the reactor.[34] Other reactor designs also offer possibilities.[35, 36] Previously, the tremendous release of heat made cooling of such reactors a big problem, but with power as a by-product, it becomes, instead, an advantage.[37, 38] Several substances, such as heavy water, may be used as both a coolant and as a moderator.[39] However, the use of either a light or heavy water (PWR) type of reactor, precludes the possibility of going to either the high temperatures or high pressures and consequent economies mentioned earlier in the case of conventional modern superpressure steam plants. This suggests the possibility of using molten metals such as sodium or NaK as a moderator and coolant. Safety factors might seem to be a deterrent in this design, but Owens and Pigott[40] conclude that a nuclear reactor can be built with no more danger to operating personnel than conventional high-pressure plants.[41] This being true, a coolant can be chosen based on its temperature and heat-removal characteristics.

From a table prepared by Bonilla[42] after the method suggested by Gilliland, Bareis and Feich,[43] sodium is the best of the various substances listed. A report prepared by Pacific Gas and Electric Company and the Bechtel Corporation and released by the AEC,[44] concludes that the liquid metal-cooled reactor best conserves uranium supply and is adapted to high-temperature high-pressure plants.

The first atomic energy plant primarily designed for the production of electric power is now under construction, near Shippingport, Pennsylvania, by the Duquesne Light Company.[45]

The reactor, which is of the PWR type, will use U^{235} to produce heat and Pu^{239}. The Pu^{239} will then be fed back as fuel. The steam will be generated at 600 psia and will drive a conventional 60-Mw turbo-alternator. Plate I-F shows the artist's concept of this plant. Early this year the Detroit Edison Company announced their proposal to construct an atomic energy power station at Lake Erie, between Toledo and Detroit.[46] The reactor will be liquid metal cooled, and will produce steam for power and plutonium. Steam will be produced at 600 psi and 500° F to drive a conventional 100-Mw turbogenerator. The Consolidated Edison Company has since applied to the AEC for a license to construct an atomic power plant at Buchan, New York, to be in operation by the fall of 1959.[47] The reactor will be of the PWR type using U^{235} to convert thorium into U^{233}, which is fissionable. Steam rating will be 236 Mw, 370 psi, 1000° F, and the plant will be by far the largest atomic plant yet proposed. Capital cost of these plants will be between $250 and $350 per installed kilowatt, with a heat rate of about 10,700 Btu per kilowatthour. Table I has been prepared by the same methods and values as appeared in the writer's former article in *The Trend*,[25] together with data from the preceding discussion. In this table, cost of power in mills per

kilowatthour for the high-pressure plant cited in 1952, is compared to the cost of power from the new supercritical pressure plant (Philo) and from a nuclear fission plant. The conventional plants are assumed to be fired by cyclone burners, using Washington subbituminous raw coal or char from a carbonization plant.[48] The nuclear plant is assumed to have a capital cost of twice the value used for the conventional plants, or $300 per kilowatt, with an equivalent fuel cost of $5.20 per ton of 9000-Btu coal. This estimate is probably low, for the present time, and perhaps should run even twice as high.[49] However, it is significant that power may be produced from a nuclear plant at from 5.74 to 11.48 mills per kilowatthour, which is far less than the cost in most of the obsolete steam plants now in use in the Northwest. As engineering skill and research are directed to this new problem, costs will surely be reduced to the point where power from conventional steam plants and from hydro is no longer competitive. One of these plants near Hanford would utilize the heat wasted there at present, and would probably be justified on this economic basis alone. Two additional factors make such a plant desirable:

1) The need for a full-scale research power project in this region.
2) The military advantage of having a plant which can produce power and/or weapons-grade plutonium.

TABLE I

MUNICIPAL, STATE, OR FEDERAL PLANT

Values in Mills/Kilowatthour

COAL-FIRED 80% Plant Factor		
Type of Expense	**1952 Plant** 1500 psi:1050° F	**Superpressure Plant** 4500 psi:1150° F/ 1050° F/1000° F
Char (Equivalent Coal at $2.60 per Ton)		
Variable (Fuel)	1.60	1.24
Fixed	2.04	2.04
Total Operating	3.64	3.28
Raw Coal at $3.50 per Ton		
Variable (Fuel)	2.18	1.68
Fixed	2.04	2.04
Total Operating	4.22	3.72
Raw Coal at $5.20 per Ton		
Variable (Fuel)	3.21	2.48
Fixed	2.64	2.04
Total Operating	5.25	4.52

NUCLEAR PLANT $300 per Kilowatt		
Type of Expense	**100% Plant Factor**	**80% Plant Factor**
Variable (Fuel)	2.48	2.48
Fixed	3.26	4.08
Total Operating	5.74	6.56

SUMMARY

The Pacific Northwest is suffering from an ever increasing power shortage which cannot possibly be alleviated by hydro construction unless supplemented by thermal plants. Conventional superpressure steam plants can be built in two years or less and can produce power in the 3.28 to 4.52 mills-per-kilowatthour range. In addition, by creating a coal or chemical derivative-coal industry in Washington, they will utilize a vast potential state resource which otherwise will have no future because of the inevitable predominance of nuclear fission power plants. Atomic plants now planned can produce power in the 5.74 to 11.48 mills-per-kilowatt-hour range by 1975. This cost will probably be reduced by research and development to the 3- to 7-mill range. Construction costs of hydro plants at sites left at that time will make them noncompetitive on an economic basis. Superpressure conventional steam plants are the answer to the power shortage now and until atomic energy plants have been developed to use the high-pressure, high-temperature reheat cycle. The vast amounts of low-grade coal in the Pacific Northwest ought to be utilized now in modern superpressure steam plants before such fuel is no longer economically useful. An atomic plant should be built now to test, by practical power production, the design factors known at present and to aid in developing the new atomic plants which will eventually furnish most of the power of the world.

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U. S. Air Force Authorizes Investigation of Cone Antennas for Jet Planes

A CONTRACT HAS BEEN NEGOTIATED between the University of Washington and the U. S. Air Force providing for an investigation of microwave antenna systems and other related problems. Professor Gedaliahu Held, of the Electrical Engineering Department, will be in charge of the project, assisted by Mr. Gerard Hasserdjian, an instructor in the department, and one or more graduate students.

Dr. Held, who is a recognized national authority in this field, will direct particular attention to the performance of cone antennas suitable for mounting on modern jet planes without seriously increasing wind resistance. He sees the problem as including four general aspects:

1. A basic study of the characteristics of a slot on a cone-shaped body, involving both a study of the fields induced in the slot and radiation caused by the induced field distributions, and a consideration of the dependence of such fields on the exciting transmission line, mode of propagation, orientation and location of the slot, and its dimensions.

2. A study of the effect of the tip of the cone. If, as seems likely, standing waves are set up between a slot in a cone and the tip of the cone, the magnitude and effect of this phenomenon should be investigated. The dependence of such standing waves on slot orientation and location should yield valuable information on the design and construction of an array.

3. A study of the possibilities of multi-mode propagation systems. The broad-band characteristic of such transmission lines and the control of slot excitation that they offer may be valuable and may lead to electrical scanning of the beam.

4. A study of the patterns of slot arrays on cones and possibilities of controlling them through slot excitation; a study of the applicability of our present knowledge of planar arrays of concentric slots to the case of concentric slots on cones; a possible study of helical long-slot antennas on the cone.

Notes and Comments

HIGHWAY EXPERT CONFERS WITH NATIONAL RESEARCH BOARD

R. G. HENNES, Professor of Civil Engineering, conferred with officials of the Highway Research Board in Washington, D. C., May 26-27. Plans for test procedures to be employed in a 12 million dollar national test road were discussed.

The experimental road, to be built next year in Illinois, will be under study for seven years. The project is sponsored by the American Association of State Highway Officials. Forty-seven states and the U. S. Bureau of Public Roads are participating.

The main objective of the test is to help in the solution of two pressing problems; how to design pavements that will carry present and future traffic loads, and what additional highway costs would be required to serve heavier trucks than are now allowed.

ENGINEERS IN THE NEWS

Dr. Gunnar V. Pleijel, on the staff of the Royal Institute of Technology at Stockholm, and member of the Swedish State Committee for Building Research, was a campus visitor May 24. He was particularly interested in inspecting the recently completed equipment for solar heat tests.

Donald C. Larson, University metallurgical engineering senior, has been named the winner of a $500 national Metal Powder Association scholarship. The scholarship is given each year to the outstanding metallurgical student in the nation who agrees to conduct thesis research in the field of powder metallurgy.

J. I. Mueller, Professor of Ceramic Engineering attended the meeting of the Pacific Northwest Ceramic Association at Victoria, B. C., May 28, where he spoke on "Effects of Atomic Blast at Yucca Flats." His paper will appear in the July issue of the PNWCA *News*.

F. B. Farquharson, Director of the Experiment Station, attended the ASCE meeting June 14-17 in St. Louis, where he met with the Task Committee on Engineering Education. June 20-24 he attended the ASEE conference at Pennsylvania State University.

R. W. Moulton, Professor and Executive Officer of Chemical Engineering, represented Engineering College Dean Wessman at the meeting of the Atomic Energy Commission Committee on Nuclear Engineering Education held at the University of Chicago, May 14.

E. C. Roberts, Associate Professor of Metallurgy, presented a paper on "Effects of Manganese on the Curie Point of Cementite," before the AIME Pacific NW Regional Conference at Spokane, April 28-30.

J. A. Higbee, Instructor in the Humanistic-Social Division, read a paper, "Is Discrimination an Engineer's Problem?" at the Regional Meeting of the ASEE held at Moscow, Idaho, April 15.

PLAIN TALK*

THE SCIENCES HAVE BECOME SO COMPLEX and workers in them have built up their own vocabularies to such an extent that a chemist has difficulty in understanding a physicist; the biologist can't talk to the geologist; none of them can talk plainly to the engineer. Sometimes the engineer can't get his ideas across to management; and few technical people can explain their aims and what they have done, to the public. Now the engineer must put the scientists' fundamental discoveries on the assembly line and ultimately the public must pay for it. This can be done quickly if each has a clear understanding of what the other is talking about. . . .

Vannevar Bush, addressing the Medical Society of the District of Columbia last year, warned that over specialization and the volume of publication are driving groups of scientists to develop their own jargon, unintelligible except to the initiated, heightening the barriers which separate their works from the main stream of progress. He said there were two concrete things that could be done about it. First, scientists could be intelligible. He said they have a moral obligation to express themselves so that they can be quickly understood by those within their profession or closely related professions. Second, those who possess that unique skill should be encouraged to gather, integrate, and interpret the information developed by many workers so that great masses of seemingly confused data become clear, intelligible and useful to their fellows. . . .

In 1846 [Michael Faraday] wrote [in his diary], "All I can say is, that I do not perceive in any part of space whether (to use the common phrase) vacant, or filled with matter, anything but forces and the lines in which they are exerted." What beautiful plain talk, twenty-nine monosyllables and eight bisyllables.†

* From the address by L. C. Beard before the American Society for Testing Materials, June 15, 1954, and published in *American Highways*, July, 1954.

† *Correction*: Twenty-nine monosyllables, seven bisyllables, one trisyllable. *Ed.*

Comparisons Made in Pairs *

THE NATIONAL BUREAU *6 STANDARDS is actively applying the methods of modern physical inference to experiments in the physical sciences and engineering. Results at NBS have shown that statistical principles and techniques are even more useful in these areas than they are in agricultural and biological work, where many of them were first developed. Much of the work deals with the design of statistically planned experiments for greater precision and accuracy. Recent studies in this field by workers in the Bureau's statistical engineering laboratory provide methods of arranging paired observations in such a way as to obtain a maximum amount of information from a minimum amount of measurement and computation.

Paired observations are important in many scientific and engineering investigations—particularly those performed under conditions not easily reproduced. Tests or measurements of this kind are often made in a group under a single set of conditions in order to avoid errors arising from environmental changes. While such a group may be of any convenient size, depending on the experimental problem, in practice it is often limited to two paired observations. For example, materials for shoe soles might be compared under actual service conditions by putting two different kinds of soles on a pair and then measuring the resulting amount of wear. Obviously the results with those worn by different people would reflect the walking habits of the wearers, and thus whole pairs would not be strictly comparable. However, the pair worn by a single individual would provide two *soles* which would be subject to very much the same amount of wear because they were used under the same conditions.

Paired observations may also be used in the testing of tires. Tires are ordinarily tested in groups of four, and daily rotation is used to equalize wheel position and differences between the surface at the center and edge of the road. However, the comparison of tire treads is greatly improved when tires are made up so that half of the circumference of each tire has a tread made with one formula and the other half has a tread made with a different formula. Practically identical conditions are then obtained in road tests of each set of paired treads. A similar pairing is used in testing paints. Here variations in the wood that is painted influence performance. For this reason, comparisons are often made by painting one end of a short board with one paint and the other end with another paint.

Difficulties arise in paired observations when more than two items need to be compared. For example, it might be desirable to compare ten different kinds of sole leather in paired service tests. The usual method is to place a common standard material in each of ten pairs. The standard serves as a go-between for the various pairs so that different materials (A, B, C, etc.) may be reasonably well compared even though they are tested under slightly different conditions. The comparison is made by taking the difference between such quantities as (A — S) and (B — S), where S is the corresponding result for the standard.

However, six materials require 12 measurements, so half of the measurement work is expended on the standard. Also, the result (A — B) involves the errors of measurements in both (A — S) and (B — S); whereas if A and B had been compared directly, only the error in measuring one difference would be involved. A more important disadvantage of this limited experiment, with six pairs for six materials under test, is the fact that there is no way of using the results to estimate the size of the errors in the comparisons. These errors might be assumed to be of the same magnitude as those between different values obtained for the standard. However, the six results for the standard may differ considerably among themselves because different conditions prevail for different pairs. The error appropriate for the comparisons would then be much smaller than the difference among the six values for S would suggest.

An alternative procedure, which gives the best relative values of the six materials and permits estimation of error, consists in forming all possible 15 pairs among the ten materials. This procedure has long been used by the National Bureau of Standards for the intercomparison of standard meter bars. The bars are compared in pairs because the constant temperature chamber accommodates only two bars. Obviously it would be very difficult to hold the chamber at exactly the same temperature for all of the measurements. However, there is no need to attempt this if the bars are placed in the chamber in all possible pairings. The 15 differences that are obtained can be written in 15 equations of the form A — B = d, involving the six unknowns A through F. A least squares solution for the the six unknowns gives the best relative values for the bars, one of which may be the standard.

* Summary of a Technical Report, National Bureau of Standards, Department of Commerce, Washington, D. C., January, 1955.

The mathematics for the least squares solution is particularly simple when all possible 15 pairs have been measured, but an immediate objection is the large number of measurements needed. To compare 15 pairs of standard meter bars in this way requires 15 days. However, a considerable reduction in the number of measurements needed is made possible by the Bureau's recent studies of paired observations. Rules were devised for picking subsets of the total array of pairs that also lead to simple least square solutions. Instead of all 15 pairs, subsets of 9 or 12 may be used. One such subset is made up of the following selection of nine pairs:

AB	EB	FB
AC	EC	FC
AD	ED	FD

Here A is paired with B, C, and D; and these three letters are in turn paired with the remaining number two letters, E and F.

Any letter is directly paired with three of the others and, through these three, indirectly paired with the remaining two letters. The 9 pairs involve three measurements on each object. The usual procedure, which calls for six pairs with a common standard, yields only one measurement on each object.

The pairs under the traditional scheme are

S	S	S	S	S	S
A	B	C	D	E	F

and comparisons between any of the letters such as A and B require that the difference between S and A be added to the difference between B and S. The nine pairs chosen in the new scheme give a *direct* and hence more precise comparison for A andB and also for the eight other pairs actually employed. There are six pairs of letters (AE, AF, BC, BD, CD, EF) not actually listed as pairs. For each of these, however, three indirect comparisons are available.
For example:

$$(A—B) + (B—E) \rightarrow A—E$$
$$(A—C) + (C—E) \rightarrow A—E$$
$$(A—D) + (D—E) \rightarrow A—E$$

Thus, by testing nine instead of six pairs there are three indirect comparisons of A and E available instead of just one.

There are other useful features connected with these designs. The nine pairs just discussed may be grouped into three sets:

1	2	3
A B	A C	A D
E C	E D	E B
F D	F B	F C

Each set of three pairs now involves all six letters. If these are pairs of shoes, one set might be assigned to grade school boys, one set to high school boys, and the remaining set to adults. By taking the *sums* of the six readings associated with any set, a measure of wear as related to age group is available without interfering with the comparison of materials. The same data are thus used for two purposes.

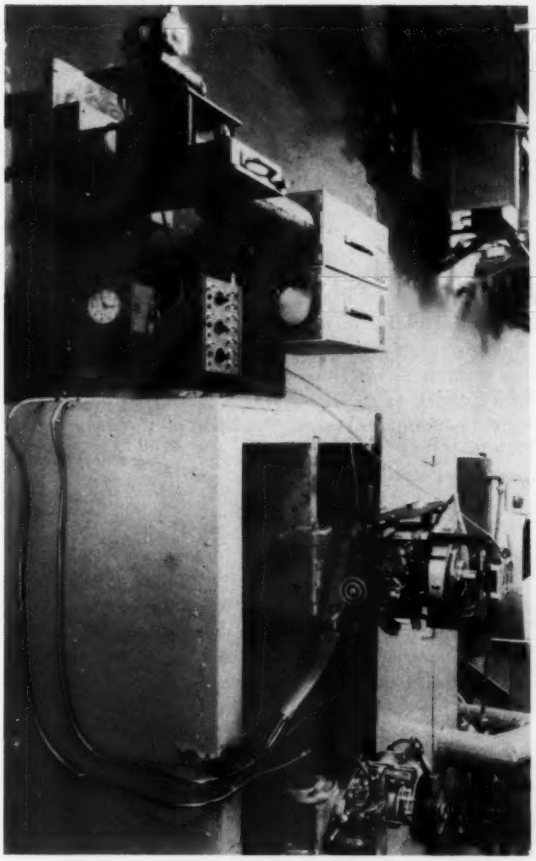

Figure 1. Apparatus used at the National Bureau of Standards in recent studies of outboard engine spark plugs. Two of the set of four test engines may be seen at right. Spark plug conductance is shown on the oscilloscopes at left during the nonsparking part of the engine cycle. A strip film camera and stop clock (*left foreground*) record and time the oscilloscope traces. A statistical arrangement was worked out which tends to equalize any differences arising from the two cylinder positions or from variations between engines.

Recent studies of spark plugs at the Bureau made use of one of these arrangements. Six types of spark plugs were involved. They were tested in four two-cylinder outboard motors, each motor having one cylinder above the other. An arrangement of the plugs in cylinders and engines which equalizes possible differences arising from cylinder position or from differences among engines is shown below:

	Run	Cylinder Top	Cylinder Bottom
Engine I	1	A	B
	2	C	E
	3	D	F
Engine II	1	B	C
	2	F	E
	3	D	A
Engine III	1	A	C
	2	F	B
	3	E	D
Engine IV	1	E	A
	2	B	D
	3	C	F

The plan provides that each type of plug be used on every one of the four engines, twice in the top position and twice in the bottom position. The 12 runs accommodate 12 of the possible 15 pairings of the six types. Any one type (e.g., A) is paired with four others (e.g., B, C, D, E), and through these may be compared with the fifth plug (e.g., F) as follows:

A-B	B-F
A-C	C-F
A-D	D-F
A-E	E-F

This schedule for the arrangement of plugs in the engine makes it possible to rate all the plugs relative to one another using only the differences in performance between plugs on the same run. The schedule also makes it possible to compare engines because the average for each engine is based on all six plugs. The effect of cylinder position can be evaluated because all six plugs are used twice in each position. Thus the data, besides serving the primary purpose of comparing spark plug performance, are used to reveal additional information about the experimental equipment used in the tests.

Strength of Trussed Columns

(Continued from page 23)

α is less than the critical angle, the column strength has been increased, from 2.5 times for T_0=5 lb, to 3.5 times for T_0=30 lb. These two curves seem to show a trend which needs to be explored further.

In Fig. 3, we have the strength of the column, P, in pounds again, as ordinates, with the angles α as abscissas. This figure definitely indicates the increase in the column strength as the angle α is increased.

Conclusion

These tests, intended for a pilot investigation with a modest goal, turned out to be quite conclusive. The results show that column strength is increased by trussing. For the practical range of α angles, it may be said that the strength of a column can be at least doubled. When the α angles are small, the tension in one set of the trussing wires or rods becomes large, and the strength of the column, in that case, is dependent on their strength.

STRUCTURAL BEHAVIOR OF BEAM AND COLUMN JOINTS

(Continued from page 25)

that the stress-strain relation of plaster in general is linear up to the point of rupture. The material is relatively weaker in tension than compression and failure seems to occur at the weakest tension side and for practical purposes may be considered to be nearly independent of the magnitude of the other principal stresses. Although these plaster-model tests were preliminary to more expensive and ambitious tests of reinforced concrete building frames to be carried out in the future, the two series under ultimate loads will surely prove to be quite different in testing results, and hence the tests of plaster model-frames have a place in the over-all study of structural behavior of building frames.

NANEVICZ, S. J., "An Investigation of the Statistical Methods of Generalized Harmonic Analysis and Their Applications to Problems in Airplane Dynamics." M.S. in Aeronautical Engineering, 1955.

This paper presents the results of an investigation of the solution of problems in airplane dynamics involving functions of a random nature by statistical methods. The basic nature of problems requiring this type of solution is presented, and the ways in which such problems can arise are discussed. The concept of a power spectrum as a statistical description of a random function to a random disturbance is described. A review is made of the basic fundamentals of probability, and the use of these concepts in determining the probability of excessive values of response amplitude is discussed. Examples of the ways in which statistical methods can be applied to problems in airplane dynamics are presented. The experimental techniques employed in obtaining power spectra are discussed, together with the results of an experiment conducted in an attempt to measure the power spectrum of a random function.

NEW PROJECTS

Project No. 180. A Dynamic Study of Transitor Characteristics for Large Signal Operation. W. R. Hill, Professor of Electrical Engineering, Supervisor; T. L. Chou, Research Assistant.

Project No. 181. Heat Transfer Coefficients at Supersonic Speeds and Low Reynolds Numbers. R. E. Street, Associate Professor of Aeronautical Engineering, Supervisor; Don Graf, Research Assistant.

Project No. 182. Triaxial Stress on Rubber. J. B. Morrison, Associate Professor of Mechanical Engineering, Supervisor.

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